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(54) **Title:** SHEAVE MONITOR

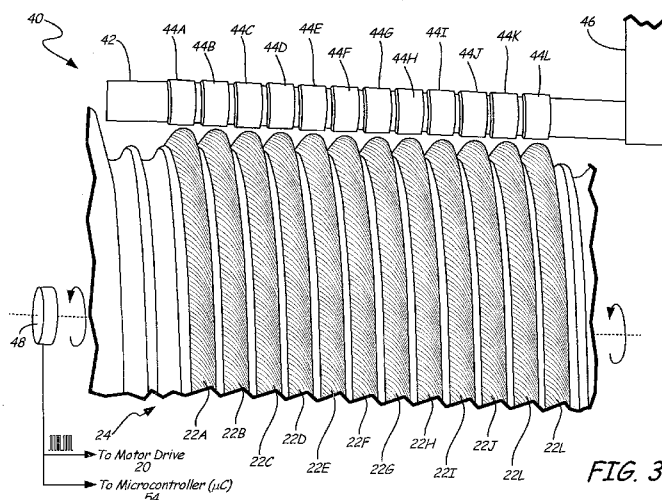


FIG. 3

(57) **Abstract:** A sheave monitor is disclosed. The condition of one or more grooves (34A-34E) in a sheave (24) of an elevator system is monitored by electrodes (44A-44L) that are positioned opposite the elevator ropes (22A-22E) positioned in the grooves (34A-34E). A monitor (50), connected to the electrodes and the motor encoder (48), provides an indication of groove condition in the circumferential direction based upon the capacitance between each rope and the electrode opposite that rope as well as rotation angle detected by the motor encoder (48). The monitor may provide a minimum cutting reference for sheave regrooving operation and also act as a rope guard.



SHEAVE MONITOR

BACKGROUND

5 The present invention relates to elevator systems, and more particularly to a monitoring system for elevator sheaves that are subjected to wear during use.

 A conventional traction elevator system typically includes a car, a counterweight, two or more tension members (such as round ropes) interconnecting the car and counterweight, a sheave to move the ropes, and a machine to rotate the sheave. The
10 machine may be either a geared or gearless machine. A geared machine permits the use of a higher speed motor, which can be more compact and less costly. The sheave typically has a set of grooves, with each rope engaging one of the grooves.

 The ropes are often formed from laid or twisted steel wire, and the sheave is often formed from cast iron. Conventional steel rope and cast iron sheaves have proven to
15 be very reliable and cost effective. One limitation of these arrangements is the traction forces between the ropes and the sheaves. Differential tension on each side of the sheave, or rope deformation due to the tension applied, or misalignment of the sheave, can all cause relative motion between the ropes and the sheave. The contact plus relative motion results in wear of the sheave and wire ropes. This wear can vary from groove to groove and from
20 rope to rope. Changes in groove depths and runout caused by wear can result in low ride quality in the elevator.

 The presence of sheave and rope wear is typically checked during periodic maintenance performed on the elevator system. The presence of metal shavings under the traction drive sheave is one indication of wear of the sheave grooves or the ropes, or both.
25 Unusual rope vibration or slippage while running or when the elevator stops can be observed in the machine room, and may indicate unequal sheave groove diameters or unequal rope tension.

 This inspection for sheave and rope wear involves on-site manual observation and inspection, which is not precise and is not continuous or real time
30 monitoring. It also involves removing the machine guard and running the machine at inspection speed.

 Sheave wear and rope wear always worsen and accelerate over time. Furthermore, sheave wear is never self-correcting. It is not unusual to see rope life reduced

by half with each succeeding set of ropes used in the elevator system as increasingly worn grooves in the sheave accelerate rope wear.

Sheave regrooving involves machining the grooves of the sheave to reestablish all of the grooves with the same profile and diameter. Sheave regrooving may be done as a proactive step during hoist rope replacement, or in an attempt to correct problems with sheave wear.

Generally, sheave regrooving occurs in conjunction with hoist rope replacement, although it can also be performed while retaining existing hoist ropes. When done early (before groove wear becomes too extreme) little material is removed and the regrooving is performed very quickly. The sheave grooves can be restored to essentially “new” condition. Regrooving can greatly improve rope and sheave life over time. New ropes running on regrooved sheaves give a rope life similar to that of an original installation. Conversely, new ropes running in worn grooves have a reduced life from the continual pinching and sliding action of neighboring ropes running over different groove diameters.

SUMMARY

The condition of a sheave is monitored by sensing distance between a sensor positioned adjacent the sheave and a rope positioned in a groove of the sheave. A monitor connected to the sensor provides an indication of groove condition based upon the sensed distance.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is perspective view of an elevator system having a traction drive and a hoistway.

FIG. 2A shows a sheave with grooves in good condition and ropes of equal rope height.

FIG. 2B shows a sheave having grooves in worn condition exhibiting unequal rope heights.

FIG. 3 shows a sheave and a multi-electrode sensor for sensing groove wear and runout.

FIG. 4 is electrical block diagram of a monitoring system including the multi-electrode sensor and a clearance monitor for monitoring sheave groove wear and abnormal runout.

FIG. 5 is a diagram illustrating regrooving an out-of-round worn groove profile.

DETAILED DESCRIPTION

FIG. 1 shows elevator system 12, which includes car 14, counterweight 16, traction drive 18, and machine or motor drive unit 20. Traction drive 18 includes ropes 22, which interconnect car 14 and counterweight 16, and grooved traction sheave 24. Elevator system 12 as shown in FIG. 1 is a 1:1 rope system. The invention does not depend on the specific rope system but functions to monitor sheave condition in any rope system, such as 2:1 rope systems and any other elevator system where sheaves and ropes or other tension members are employed. In addition, the present invention is not limited to use in an elevator system. The present invention could be used in any system in which a rope passes over a sheave (in other industries referred to as a pulley).

As seen in FIG. 1, ropes 22 are engaged with grooved sheave 24 such that rotation of sheave 24 moves ropes 22, and thereby car 14 and counterweight 16. Machine 20 is engaged with sheave 24 to rotate sheave 24. Although machine 20 is shown as a geared machine, it is noted that this configuration is for illustrative purposes only, and the present invention may be used with geared or gearless machines and with other elevator systems. All that is required is that there is a grooved sheave and ropes that engage the grooves of the sheave. Elevator system 12 is located below machine room 26 and inside hoistway 28, illustrating a typical but not limiting arrangement of the elevator inside a building.

FIGS. 2A and 2B show the effects of sheave groove wear and runout. In FIGS. 2A and 2B, a portion of sheave 24 is shown in section, with outer rim 30 and central web 32. In this example, rim 30 of sheave 24 has five circumferential grooves 34A-34E, which are engaged by five wire ropes 22A-22E, respectively. Of course, the present invention could be used with any number of ropes.

FIG. 2A shows sheave 24 in good condition. As can be seen in this example, ropes 22A-22E have equal or nearly equal rope height, as shown by reference line R, which touches the top surface of each of ropes 22A-22E.

FIG. 2B illustrates sheave 24 in a worn condition. In this case, grooves 34C and 34E are shown as having experienced greater wear than grooves 34A, 34B, and 34D. As a result, gap G1 exists between rope 22C and reference line R. Similarly, gap G2 exists between rope 22E and reference line R. Rope wear can also cause a gap, due to a change in rope diameter. Actually, both sheave 22 and ropes 22A-22E wear during their life cycle, but sheave wear is more significant than rope wear. The sheave material (cast iron) is softer than rope material (hard-drawn steel), and the engaged length of sheave is much shorter than that of ropes, which results in a higher wear rate of sheave grooves.

The wear around the circumference of sheave rim 30 may vary. These variations can result from slight differences in composition or presence of small imperfections at different locations around the circumference of rim 30. These differences can result in uneven wear, so that the rope height will vary as sheave 24 rotates through 360°. This variation is referred to as runout.

Determining whether sheave and rope wear is present, and whether runout exists, can be performed with on-site manual observation. However, this type of inspection occurs only periodically and is dependent upon the skill of the operator visually observing differences in rope height and determining whether corrective action is needed. The present invention provides the ability to detect and monitor in real time the total groove and rope wear and runout of a sheave in an elevator system. Monitoring is done electrically, and can be used to provide an alarm or to report to an elevator monitor system when total groove/rope wear or runout has reached a point at which corrective action or maintenance is needed.

FIG. 3 shows sheave 24 together with multi-electrode sensor 40 for electrically sensing groove/rope wear and runout. FIG. 3 is broken away to show only a portion of sheave 24, together with ropes 22A through 22L positioned in circumferential grooves of sheave 24. Sensor 40 includes support bar 42 and an array of sensing electrodes 44A-44L along the support bar 42. Each electrode 44A-44L is aligned with and spaced from one of the ropes 22A-22L, respectively. Support bar 42 may be supported at both ends, or just one end. Support bar 42 provides support to electrodes 44A-44L, so that when sheave 24 and ropes 22A-22L are in good condition, the spacing between the respective ropes 22A-22L and electrodes 44A-44L will be equal. In one embodiment, support bar 42 is a metal (e.g. steel) rod with an electrical insulation coating, and electrodes 44A-44L are electrically conductive (e.g. metal) rings on the insulation coating.

Ropes 22A-22L are metallic wire ropes, and are electrically conductive. Sheave 24 is also electrically conductive. By electrically grounding sheave 24, ropes 22A-22L are at a common electrical potential.

Each electrode-rope pair forms an individual capacitance sensor. The
5 capacitance sensed is a function of the gap between the electrode and the rope. As the sheave grooves wear, the gap will increase, and the capacitance will decrease. As sheave 24 rotates, any runout in a particular groove will result in a varying capacitance as sheave 24 rotates through 360°.

In other embodiments, monitoring of only one, or a selected number of
10 ropes/grooves, may be done, rather than having a capacitance sensor for each rope/groove. In that case, the capacitance sensor(s) for the ropes/grooves being monitored will be considered to be representative of the wear and runout being experienced by all ropes/grooves.

Support arm or mount 46 provides physical support for bar 42. In addition,
15 the individual electrical leads from electrodes 44A-44L can extend along or through bar 42 and then on or through support arm 46 to a clearance monitor that processes the individual capacitance sensor signals. Support arm 46 can be attached to any stationary structure that is near sheave 24, and can take a variety of different shapes.

Bar 42 can be fixed on machine to replace conventional rope guard. It
20 prevents rope from jumping as rope guard does. If the rope jumps so high due to excessive car/counterweight vibration that it contacts the electrode, the gap closes and a short circuit occurs. Thus the monitoring system will detect the situation.

Also shown in FIG. 3 is encoder 48, which is installed on machine 20. Encoder 48 outputs encoder pulses and feeds back sheave position to the motor drive of
25 machine 20 when the motor shaft (and therefore sheave 24) is rotating. In one embodiment, for example, encoder 48 provides 8192 encoder pulses/revolution. The output of encoder 48 may also be used by the sheave monitor to identify runout location and to guide re-grooving to eliminate runout.

FIG. 4 is an electrical block diagram of the sheave wear and runout system.
30 Shown in FIG. 4 are capacitances CA-CL, which represent the capacitance between ropes 22A-22L and corresponding electrodes 44A-44L, respectively. In this diagram, ropes 22A-22L are depicted as the lower plate of each capacitance CA-CL, respectively, and are connected to a reference potential such as ground. Electrodes 44A-44L are represented by

the upper plate of capacitances CA-CL, respectively, and are connected to clearance monitor 50.

In the embodiment shown in FIG. 4, clearance monitor 50 includes capacitance-to-frequency (C/F) converter 52 and microcontroller 54. Clearance monitor 50
5 communicates with alarm 56 and with elevator monitor system 58.

C/F converter 52 converts the sensed capacitance of each capacitor CA-CL to a sensor signal FA-FL having a frequency that is a function of the corresponding sensed capacitance CA-CL. C/F converter 52 may include an individual capacitance-to-frequency conversion circuit for each capacitive sensor, or may include a multiplexer that selectively
10 connects one capacitive sensor at a time to a capacitance-to-frequency converter.

The sensor signals from C/F converter 52 are received by microcontroller 54, and are processed to provide a measure of the gap between each electrode 44A-44L and corresponding rope 22A-22L, respectively.

During machine installation in the hoistway, clearance monitor 50 will
15 measure the initial capacitance values representing the clearance gaps between ropes 22A-22L and electrodes 44A-44L. Microcontroller 54 stores those initial reference measurements for comparison with subsequent measurements. For example, the initial clearance gaps may be on the order of about 5 mm.

Clearance monitor 50 can make real time measurements of clearance
20 (capacitance) during operation of the elevator system. These measurements can be done on a continuous basis when the elevator is subject to high use, or may be done on a periodic basis. The measurements can be made when sheave 24 is not rotating to provide an indication of groove wear, and can be made while sheave 24 is rotating to provide an indication of runout. Microcontroller 54 can compare real time measurements to stored
25 reference measurements to provide real time data indicating changes in the amount of wear or runout. The data can also indicate not only the existence of runout or wear, but also the particular groove or grooves that are involved.

When the capacitance change from the initial reference is greater than a preset value, or the runout is greater than a preset value, microcontroller 54 may provide an
30 output signal to alarm 56. Microcontroller 54 may also report the results of its measurements periodically to elevator monitor system 58. The data received by elevator monitor system 58 can be communicated to an inspector at a remote site, and can be used for scheduling maintenance for the sheave and the ropes.

Although FIG. 4 shows the use of C/F converter 52, other signal processing circuitry can be used to convert the sensed capacitances to sensor signals that can then be processed by microcontroller 54. For example, capacitance-to-voltage or capacitance-to-digital converter circuitry could also be used to produce sensor signals for processing by microcontroller 54.

Microcontroller 54 also reads the encoder pulse signal from encoder 48. With synchronous position provided by encoder 48 and gap signals from electrodes 44A-44L, the microcontroller 54 can determine specific sheave wear in the circumferential direction. Guided by the monitor system, mechanics can find the zero (minimum) cutting position and adjust the cutting edge aligned with the circumference reference, which has a minimum cutting and minimum sheave diameter reduction for re-grooving operation, as shown in FIG. 5.

In FIG. 5, solid line 70 represents a worn groove profile in the circumferential direction. Worn groove profile data representing the profile of solid line 70 can be stored by microcontroller 54 based upon gap sensor data and corresponding encoder data. Solid line 70 shows runout, i.e. the radius of the worn groove varies in the circumferential direction, with a minimum radius at point A, and a maximum radius at point B.

Dashed line 80 shows a desired re-grooved profile in which runout has been eliminated. In other words, dashed line 80 has a circular profile with a uniform radius around the entire 360° circumference of the groove.

FIG. 5 also shows re-grooving tool T, which is used to create the profile shown by dashed line 80. The depth of tool T will be determined by using point A (identified by the data from microcontroller 54 as the minimum cutting point).

The present invention provides real time monitoring of rope/sheave wear and runout. It does not require on-site manual observation and inspection by service personnel. The sensing of gap between the electrodes and the ropes based upon capacitance is more precise than manual visual observation, and is far less prone to human error. The monitoring of rope/sheave wear and runout occurs during normal operation of the elevator, and does not require any special steps such as removing a machine guard and running the machine at inspection speed in order to evaluate wear and runout. In addition, the monitoring device may also function as a rope guard.

While the invention has been described with reference to an exemplary embodiment(s), it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular
5 situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment(s) disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

CLAIMS:

1. A system for monitoring a condition of a sheave having a groove for receiving and engaging a rope, the system comprising:
a sensor for mounting adjacent the sheave so that the sensor is positioned
5 opposite and spaced from the rope;
a monitor for providing an indication of groove condition based upon sensed distance between the rope and the sensor opposite that rope.
2. The system of claim 1, wherein the sensor is a capacitive sensor that exhibits
10 a capacitance that is a function of the distance between the rope and the sensor, and the monitor compares sensed capacitance with a reference value.
3. The system of claim 2, wherein the reference value represents a capacitance
15 corresponding to an initial clearance between the rope and the sensor.
4. The system of claim 2, wherein the monitor produces an output when the sensed capacitance has changed with respect to the reference value by greater than a preset value.
- 20 5. The system of claim 4, wherein the monitor provides the output to an elevator monitor system.
6. The system of claim 4, wherein the monitor provides the output to an alarm.
- 25 7. The system of claim 2, wherein the monitor includes:
capacitance-to-frequency circuitry connected to the capacitive sensor to
provide a signal that has a frequency that is a function of capacitance
between an electrode of the capacitance sensor and an adjacent rope.
- 30 8. The system of claim 7, wherein the monitor includes:
a microcontroller that converts the frequency to a sensed capacitance value.

9. The system of claim 1, wherein the monitor determines runout of the groove based upon variation in the sensed distance as the sheave rotates.
10. The system of claim 1 and further comprising:
5 a bar, positioned parallel to a rotational axis of the sheave and spaced from the ropes, for supporting the sensor.
11. The system of claim 10 and further comprising:
a mount for supporting the bar with respect to the sheave.
- 10 12. The system of claim 1 and further comprising:
an encoder for providing encoder data indicating rotational position of the sheave to the monitor.
- 15 13. The system of claim 12, wherein the monitor stores data representing a worn groove profile based on sensed distance data and encoder data for guiding re-grooving of the sheave.
14. The system of claim 12, wherein the monitor determines runout of the sheave
20 based on the sensed distance data and the encoder data.
15. A system for monitoring a condition of a sheave having a groove, the system comprising:
an electrode;
25 a support for positioning the electrode in a spaced relationship to the sheave with the electrode spaced from a rope in the groove; and
a monitor for providing an indication of condition of the groove based upon sensed capacitance between the rope and the electrode.
- 30 16. The system of claim 15, wherein the monitor compares sensed capacitance with a reference value that represents a capacitance corresponding to an initial clearance between the rope and the electrode.

17. The system of claim 15, wherein the monitor produces an output when capacitance between the rope and electrode has changed by greater than a preset value.
18. The system of claim 15, wherein the monitor includes:
5 capacitance-to-frequency circuitry connected to the electrode to provide a signal that has a frequency that is a function of capacitance between that electrode and the rope; and
a microcontroller that converts the frequency to a sensed capacitance value.
- 10 19. The system of claim 15, wherein the monitor determines runout of the groove based upon variation of the sensed capacitance as the sheave rotates.
20. The system of claim 19, wherein the monitor stores data representing a worn groove profile based on the variation of the sensed capacitance as the sheave rotates.
- 15 21. A method of monitoring a condition of a sheave, the method comprising:
sensing capacitance between a rope positioned in a groove of the sheave and an electrode positioned radially outward from and aligned with the rope and the groove; and
20 providing an indication of condition of the sheave based upon the sensed capacitance.
22. The method of claim 21, wherein providing an indication of condition of the elevator sheave comprises:
25 comparing the sensed capacitance to a reference value; and
providing an indication of wear of the groove based upon the comparison.
23. The method of claim 21, wherein providing an indication of condition of the elevator sheave comprises:
30 monitoring the sensed capacitance as the sheave rotates; and
providing an indication of runout based upon variation of the sensed capacitance as the sheave rotates.

24. The method of claim 21 and further comprising:
storing worn groove profile data based upon variation of the sensed
capacitance as the sheave rotates; and
guiding re-grooving of the sheave based upon the worn groove profile data.
- 5
25. The method of claim 21, wherein providing an indication of the elevator
sheave comprises:
providing an output to at least one of an alarm and an elevator monitoring
system.
- 10
26. A rope guard for a sheave having a groove that receives a rope, comprising:
a bar positioned in spaced relationship to the sheave to retain the rope in the
groove; and
a sensor on the bar for sensing distance between the rope and the sensor.
- 15
27. The rope guard of claim 26, wherein the sensor monitors sheave condition
and/or contact between the rope and the bar.
28. The rope guard of claim 26 and further comprising:
a monitor that stores worn groove profile data based upon sensed distance
and rotational position of the sheave.
- 20

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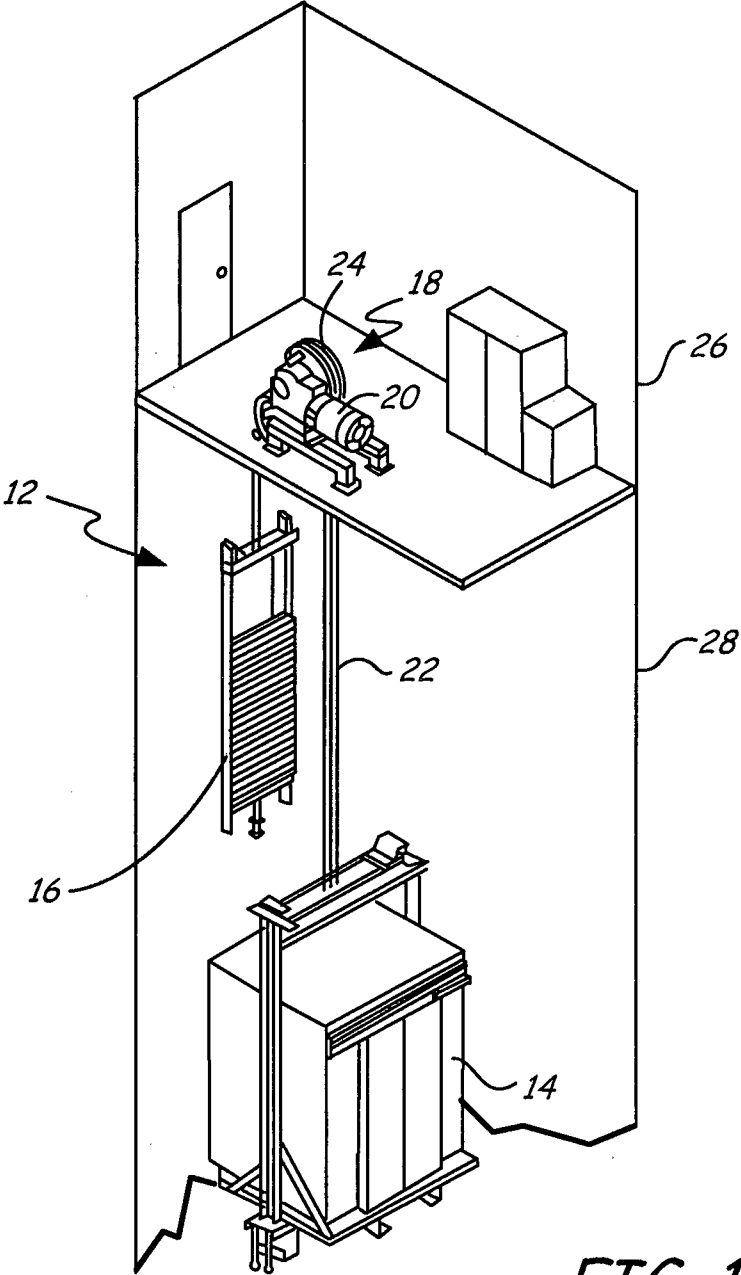


FIG. 1

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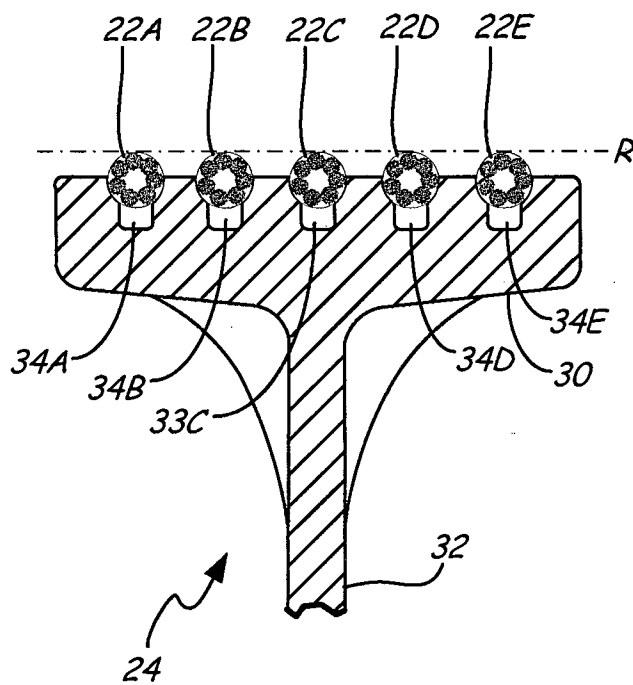


FIG. 2A

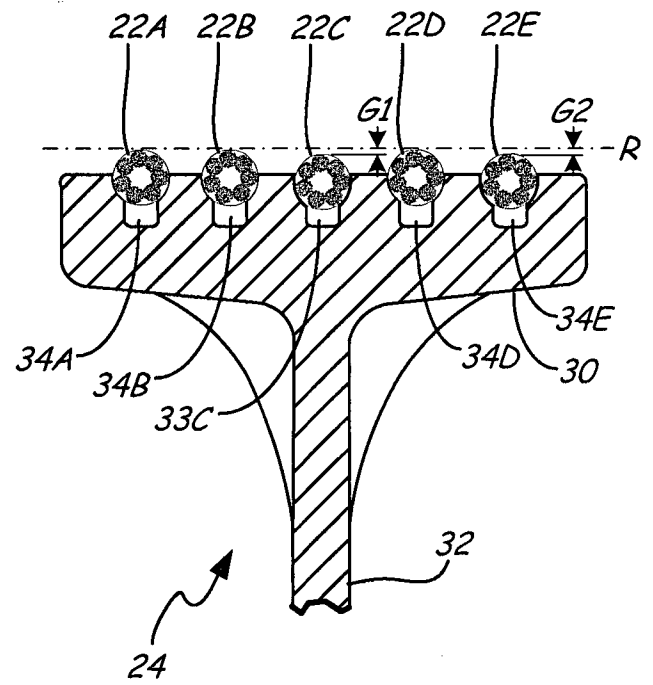


FIG. 2B

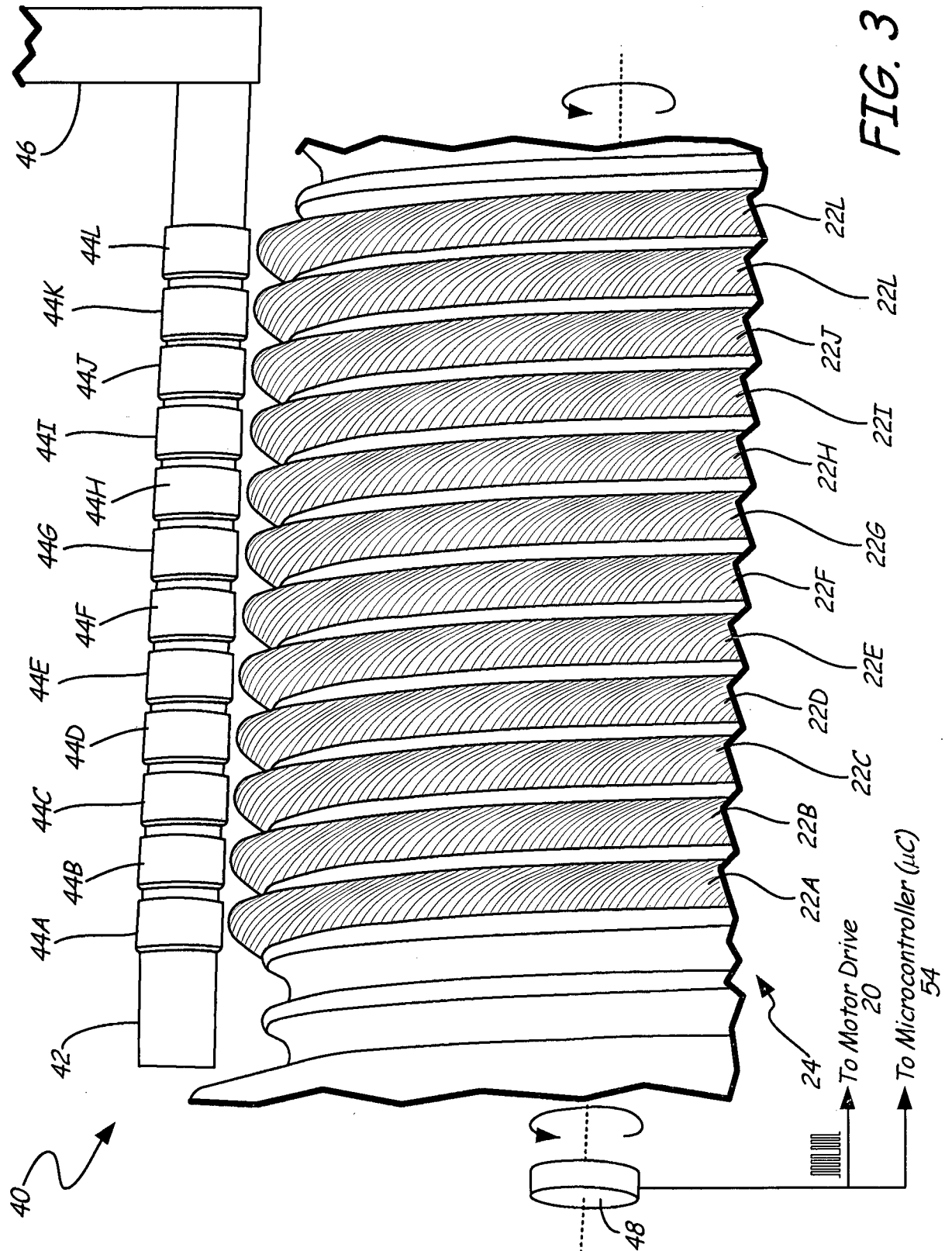


FIG. 3

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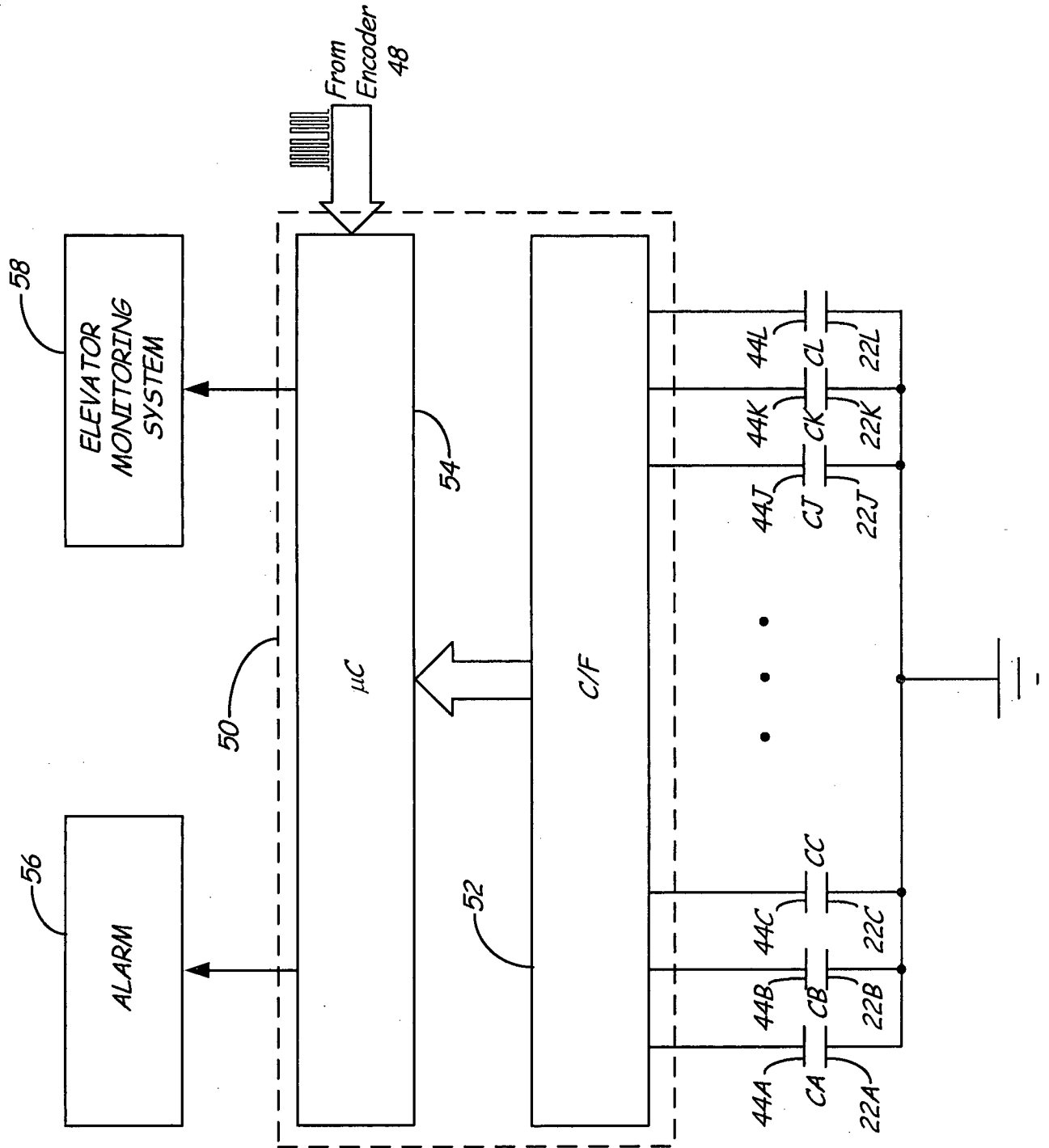


FIG. 4

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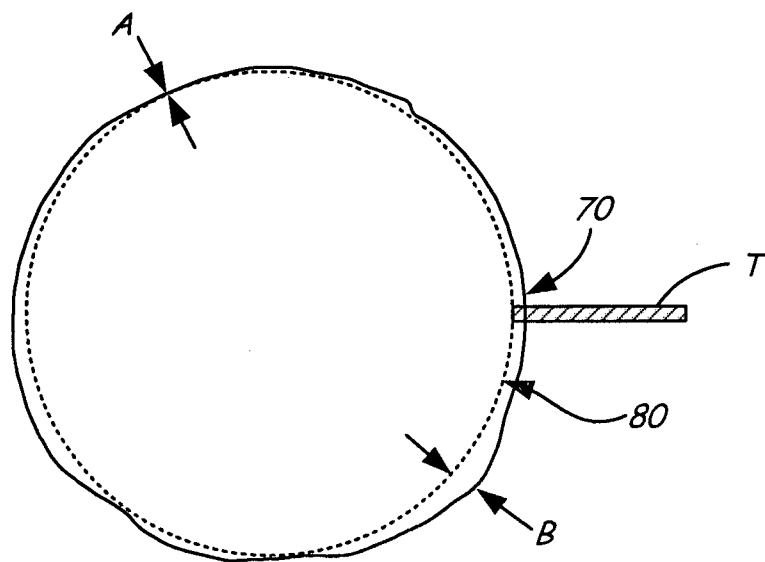


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.

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A. CLASSIFICATION OF SUBJECT MATTER

See extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: B66B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI,EPODOC,CNKI,CNPAT; rope, sheave, monitor, sensor, electrode, capacitance, distance, clearance

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2009-96571 A (TOSHIBA ELEVATOR CO LTD) 07 May 2009 (07.05.2009) See description, paragraphs 20-53 and figs.1-4	1—28
X	US 4145920 A (MITSUBISHI ELECTRIC CORP) 27 Mar. 1979 (27.03.1979) See the whole document and figs.1-6	1—28
X	JP 8-333066 A (MITSUBISHI ELECTRIC BILL TECH) 17 Dec. 1996 (17.12.1996) See description, paragraphs 26-37 and figs.1-4	1—28
X	JP 8-301543 A (MITSUBISHI ELECTRIC BILL TECH) 19 Nov.1996 (19.11.1996) See description, paragraphs 18-27 and figs.1-7	1—28
A	JP 5-105349 A (HITACHI BUILDING SYST ENG) 27 Apr.1993 (27.04.1993) See the whole document	1—28

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:	“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
“A” document defining the general state of the art which is not considered to be of particular relevance	“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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“O” document referring to an oral disclosure, use, exhibition or other means	
“P” document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 21 Feb.2012 (21.02.2012)	Date of mailing of the international search report 15 Mar. 2012 (15.03.2012)
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International application No.
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Form PCT/ISA /210 (patent family annex) (July 2009)

INTERNATIONAL SEARCH REPORT

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A.CLASSIFICATION OF SUBJECT MATTER

B66B 5/02 (2006.01) i

B66B 7/12 (2006.01) i