FILED
FEDERAL COURT
COUR FÉDÉRALE
DÉPOSÉ
October 07, 2025
07 octobre 2025
Abdoulaye Sidibe
OTT 1

Court File No.

FEDERAL COURT

B E T W E E N:

VERIFI LLC

Plaintiff

-and-

GIATEC SCIENTIFIC INC.

Defendant

STATEMENT OF CLAIM

TO THE DEFENDANT:

A LEGAL PROCEEDING HAS BEEN COMMENCED AGAINST YOU by the Plaintiff. The claim made against you is set out in the following pages.

IF YOU WISH TO DEFEND THIS PROCEEDING, you or a solicitor acting for you are required to prepare a statement of defence in Form 171B prescribed by the *Federal Courts Rules*, serve it on the Plaintiff's solicitor or, where the Plaintiff does not have a solicitor, serve it on the Plaintiff, and file it, with proof of service, at a local office of this Court:

> WITHIN 30 DAYS after the day on which this statement of claim is served on you, if you are served in Canada or the United States; or
>
> WITHIN 60 DAYS after the day on which this statement of claim is served on you, if you are served outside Canada and the United States.
>
> TEN ADDITIONAL DAYS are provided for the filing and service of the statement of defence if you or a solicitor acting for you serves and files a notice of intention to respond in Form 204.1 prescribed by the *Federal Courts Rules*.

Copies of the *Federal Courts Rules*, information concerning the local offices of the Court and other necessary information may be obtained on request to the Administrator of this Court at Ottawa (telephone 613-992-4238) or at any local office.

IF YOU FAIL TO DEFEND THIS PROCEEDING, judgment may be given against you in your absence and without further notice to you.

DATE: ISSUED BY:

Address of local office:
90 Sparks Street
Ottawa, ON K1A 0H9

TO: Giatec Scientific Inc.
245 Menten Place, Suite 300
Ottawa, Ontario
K2H 9E8

CLAIM

1. Verifi LLC (the "**Plaintiff**") claims:

   (a) a declaration that:

      (i) claims 1-17, inclusive, of Canadian Patent No. 2,930,468 (the "**468 Patent**") are valid;

      (ii) claims 1-19, inclusive, of Canadian Patent No. 3,007,480 (the "**480 Patent**") are valid;

      (iii) claims 1-17 of the 468 Patent and claims 1-19 of the 480 Patent (collectively, the "**Verifi Patents**") have been infringed by Giatec Scientific Inc. (the "**Defendant**"); and

      (iv) the Defendant has induced others, including customers and users, to infringe claims 1-17, inclusive, of the 468 Patent and claims 1-19, inclusive, of the 480 Patent;

   (b) a permanent injunction to restrain the Defendant, by itself, its directors, officers, employees, servants, agents, subsidiaries, licensees, successors, assigns, related or affiliated companies, and all those in privity with or under the direction or control of the Defendant from, directly or indirectly:

      (i) engaging in any activity that would infringe any one or more of claims 1-17 of the 468 Patent and claims 1-19 of the 480 Patent, including any prototyping, making, testing, manufacturing, importing, exporting, distributing, using, selling or offering for sale, in Canada or from Canada, of any software methods or systems or concrete delivery, monitoring, calibration, quality control or management methods or systems that would infringe any one or more of claims 1-17 of the 468 Patent and claims 1-19 of the 480 Patent, including engaging in any prototyping, making, testing, manufacturing, importing, exporting, distributing, using, selling or offering for sale, in Canada or from Canada of the Defendant's MixPilot or SmartMix products (collectively, the "**Infringing Product**"); and

(ii) inducing others to infringe any one or more of claims 1-17 of the 468 Patent and claims 1-19 of the 480 Patent, including inducing others to prototype, make, test, manufacture, import, export, distribute, use, sell or offer for sale, in Canada or from Canada, the Infringing Product;

(c) if a permanent injunction is granted, delivery up to the Plaintiff or destruction under oath of all software systems and concrete delivery, monitoring, calibration, quality control or management systems that infringe, or that when used/made infringe, any one or more of claims 1-17 of the 468 Patent and claims 1-19 of the 480 Patent, including delivery up to the Plaintiff or destruction under oath of any and all of the Infringing Products within the possession, power or control of the Defendant and which may offend the injunction sought herein;

(d) damages in excess of $50,000 or an accounting of profits that the Plaintiff may, after due inquiry, elect for infringement, and for inducing infringement, of the Verifi Patents;

(e) reasonable compensation for damage that the Plaintiff sustained by reason of any act on the part of the Defendant after the applications for the Verifi Patents became open to public inspection and before the grants of the Verifi Patents that would have constituted an infringement of the Verifi Patents had the Verifi Patents been granted on the day they became open to public inspection;

(f) the Plaintiff's costs of, and incidental to, this action at the highest scale, including all disbursements and experts' fees;

(g) pre-judgment and post-judgment interest at the maximum allowable rate on all monetary awards;

(h) Goods and Services Tax / Harmonized Sales Tax; and

(i) such further and other relief as this Honorable Court deems just.

THE PARTIES

2. The Plaintiff, Verifi LLC ("**Verifi**"), is a Delaware limited liability company with its principal place of business at 20 Moores Road, Malvern, Pennsylvania, 19355, United States of America ("**USA**"). Verifi is a developer, producer and supplier of solutions for the delivery, monitoring, calibration, quality control and management of concrete and related systems.

3. The Defendant is a corporation existing under the laws of Canada, with a registered office address at 245 Menten Place, Suite 300, Ottawa, Ontario, K2H 9E8. The Defendant is in the business of making, using, selling, offering for sale, marketing, and instructing/supporting customers and end users regarding the installation and use of hardware and software products used in the concrete industry, including the Infringing Product.

4. The Plaintiff and the Defendant are direct competitors in the concrete industry. Both the Plaintiff and the Defendant offer products across the same product segments, including software system products that relate to the delivery, monitoring, calibration, quality control and management of concrete and related systems.

THE 468 PATENT

5. Verifi is the owner of the 468 Patent, which issued on April 26, 2022, and is entitled "Determination of Gyroscopic Based Rotation". A copy of the 468 Patent is attached as **Schedule "A"**.

6. The application for the 468 Patent was filed on November 14, 2014, and claims priority to November 15, 2013 (US 61/904,680). It was laid open for public inspection on May 21, 2015.

7. Verifi has, until November 14, 2034, the exclusive right, privilege, and liberty of making, constructing, using and selling to others the invention as claimed in the 468 Patent.

8. The 468 Patent has been in full force and effect since its date of issue, namely, April 26, 2022. At all material times, Verifi has been the exclusive owner of the 468 Patent. The

Plaintiff pleads and relies on the presumption of validity of the 468 Patent pursuant to subsection 43(2) of the *Patent Act*.

THE 480 PATENT

9. Verifi is the owner of the 480 Patent, which issued on March 28, 2023, and is entitled "Wide Speed Range Concrete Monitoring Calibration". A copy of the 480 Patent is attached as **Schedule "B"**.

10. The application for the 480 Patent was filed on December 7, 2015. It was laid open for public inspection on June 15, 2017.

11. Verifi has, until December 7, 2035, the exclusive right, privilege, and liberty of making, constructing, using and selling to others the invention as claimed in the 480 Patent.

12. The 480 Patent has been in full force and effect since its date of issue, namely, March 28, 2023. At all material times, Verifi has been the exclusive owner of the 480 Patent. The Plaintiff pleads and relies on the presumption of validity of the 480 Patent pursuant to subsection 43(2) of the *Patent Act*.

THE DEFENDANT'S INFRINGING ACTIVITIES

13. The Defendant makes, uses, sells, and offers for sale in, from and to Canada, and exports from Canada, software methods and systems and concrete-related products, methods and systems, including the Infringing Product, intended for delivery, monitoring, calibration, quality control and management of concrete during its production, delivery, and use.

14. The Defendant markets and promotes its products, methods and systems as described herein, including the Infringing Product, to customers and potential customers in various forms, including in product literature published on the Defendant’s website and in digital media on YouTube.com.

15. The Defendant publishes, shares and disseminates information that directs consumers as to how to work and operate its products, methods and systems as described herein, including the Infringing Product. For example:

(a) The Defendant publishes, shares and disseminates information that directs customers and users on the process of how its products, methods and systems as described herein, including the Infringing Product, derive data, how that data is transmitted and consolidated, how the data is implemented, and how its customers can benefit;

(b) The Defendant also publishes and makes available to customers and users additional details in product literature pertaining to its products, methods and systems as described herein, including the Infringing Product, that encourages such consumers to oversee the quality of their concrete at every stage of the concrete lifecycle;

(c) The Defendant also advertises its products, methods and systems as described herein, including the Infringing Product, at national and international events and conferences, including those scheduled for 2025-2026 in Canada, England, the United Kingdom, the USA, and Saudi Arabia;

(d) The Defendant also publishes podcasts onto various media platforms, including Amazon Music, Apple Podcasts, and Spotify, that encourage consumers to acquire and use, and that explain the benefits of, the Defendant's products, methods and systems as described herein, including the Infringing Product. Such podcasts also direct consumers regarding how they can tailor such benefits to reflect situation-specific conditions; and

(e) The Defendant further advertises to consumers that it has "the biggest data set that's available on earth for concrete performance" and that data used for its products, methods and systems as described herein, including the Infringing Product, is collected through the Defendant's in-situ monitoring sensors and their partners.

16. At a time known to the Defendant, but in any event after the publication of the applications for the Verifi Patents and at least as early as January 2021, the Defendant engaged in the prototyping, making, testing, manufacture, sale, offering for sale, exportation, distribution, use, and inducement to prototype, make, test, manufacture, import, export, sell, offer for sale, distribute and use within, from and to Canada its products, methods and systems as described herein, including the Infringing Product, such that the Defendant has infringed and induced others to infringe all claims of the Verifi Patents, as particularized below. All of the foregoing activities of the Defendant as further discussed and particularized herein were carried out with a commercial intent and purpose.

17. Additional Infringing Products beyond those identified above or herein are within the knowledge of the Defendant, and are not currently known to the Plaintiff. However, the Plaintiff claims in respect of all such products.

18. The Infringing Product comprises a gyroscopic rotational monitoring system comprising:

(a) a gyroscope coupled to a rotatable concrete mixer drum having spirally-mounted mixer blades and an axis of rotation, the gyroscope for providing a first signal corresponding to a rate of rotation of the mixer drum;

(b) a periodicity sensor coupled to the rotatable concrete mixer drum, the periodicity sensor for providing a second signal corresponding to a period of rotation of the concrete mixer drum;

(c) a processor; and

(d) memory coupled to the processor, the memory comprising executable instructions that when executed by the processor cause the processor to effectuate operation of the concrete mixer drum having the spirally-mounted mixer blades, whereby rotation of the mixer drum in a first direction causes contents of the drum to be mixed, and whereby rotation of the mixer drum in a second direction opposite the first direction causes the contents of the drum to be expelled from the drum, the instructions executable by the processor comprising:

(i) receiving the first signal;

(ii) receiving the second signal;

(iii) determining calibration information based on the received first signal and the received second signal; and

(iv) generating an output signal corresponding to a calibrated rate of a rotation of the concrete mixer drum based on the calibration information.

19. Therefore, the Defendant’s prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 1 of the 468 Patent.

20. In addition, the Infringing Product comprises a gyroscopic rotational monitoring system wherein the gyroscope comprises a Micro-Electro Mechanical System (MEMS). Therefore, the Defendant’s prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 2 of the 468 Patent.

21. In addition, the Infringing Product comprises a gyroscopic rotational monitoring system wherein the rate of rotation is an angular velocity of the rotatable concrete mixer drum. Therefore, the Defendant’s prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 3 of the 468 Patent.

22. In addition, the Infringing Product comprises a gyroscopic rotational monitoring system wherein the gyroscope, the periodicity sensor, and the processor are located within

a common housing enclosure mounted onto the rotatable concrete mixer drum. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 4 of the 468 Patent.

23. In addition, the Infringing Product comprises a gyroscopic rotational monitoring system wherein the gyroscope is mounted on the concrete mixer drum at a distance from the rotational axis of the concrete mixer drum. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 5 of the 468 Patent.

24. In addition, the Infringing Product comprises a gyroscopic rotational monitoring system wherein the accelerometer is mounted on the concrete mixer drum at a distance from the rotational axis of the concrete mixer drum. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 6 of the 468 Patent.

25. In addition, the Infringing Product comprises a gyroscopic rotational monitoring system wherein the periodicity sensor comprises an accelerometer. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 7 of the 468 Patent.

26. In addition, the Infringing Product comprises a gyroscopic rotational monitoring system wherein the at least one periodicity sensor comprises a hydraulic pressure sensor. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing,

using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 8 of the 468 Patent.

27. In addition, the Infringing Product comprises a gyroscopic rotational monitoring system wherein the instructions executable by the processor further comprise:

(a) transmitting an indication of the calibrated rate of rotation of the concrete mixer drum.

28. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 9 of the 468 Patent.

29. In addition, the Infringing Product comprises a gyroscopic rotational monitoring system wherein the instructions executable by the processor further comprise:

(a) determining whether the second signal is stable, wherein when the second signal is stable the gyroscope is calibrated.

30. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 10 of the 468 Patent.

31. In addition, the Infringing Product comprises a gyroscopic rotational monitoring system wherein it further comprises a concrete slump monitoring system, the slump monitoring system comprising:

(a) a second processor, the second processor configured to receive the output signal corresponding to the calibrated rotational rate provided by the processor; and

(b) an energy sensor operably connected to the second processor, the energy sensor for measuring the energy required to rotate the rotatable mixer drum.

32. Therefore, the Defendant’s prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 11 of the 468 Patent.

33. In addition, the Infringing Product comprises a gyroscopic rotational monitoring system wherein the rotatable concrete mixer drum is mounted onto a truck. Therefore, the Defendant’s prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 12 of the 468 Patent.

34. In addition, the Infringing Product comprises a gyroscopic rotational monitoring system wherein the gyroscope is configured to provide the first signal to the processor numerous times within a single rotation of the concrete mixer drum. Therefore, the Defendant’s prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 13 of the 468 Patent.

35. In addition, the Infringing Product comprises a gyroscopic rotational monitoring system wherein the instructions executable by the processor further comprise:

(a) determining a calibration constant, to determine stability of either the gyroscope or periodicity sensor, while the drum is rotating at different speeds.

36. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 14 of the 468 Patent.

37. In addition, the Infringing Product comprises a gyroscopic rotational monitoring system wherein the axis of rotation is between 10 and 20 degrees with respect to ground. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 15 of the 468 Patent.

38. The Infringing Product comprises a gyroscopic rotational monitoring system comprising:

(a) a gyroscope coupled to a rotatable mixer drum having spirally-mounted mixer blades and an axis of rotation, the gyroscope for providing a first signal corresponding to a rate of rotation of the mixer drum, the mixer drum being effective for mixing a displaceable material chosen from powders, particles, grains and seeds, cereals, coffee, detergents, pharmaceutical materials, and concrete;

(b) a periodicity sensor coupled to the rotatable mixer drum, the periodicity sensor for providing a second signal corresponding to a period of rotation of the mixer drum;

(c) a processor; and

(d) memory coupled to the processor, the memory comprising executable instructions that when executed by the processor cause the processor to effectuate operation of the mixer drum having the spirally-mounted mixer blades, whereby rotation of the mixer drum in a first direction causes contents of the drum to be mixed, and whereby rotation of the mixer drum in a second direction opposite the first direction causes the contents of the drum to be expelled from the drum, the instructions executable by the processor comprising:

  (i) receiving the first signal;

  (ii) receiving the second signal;

  (iii) determining calibration information based on the received first signal and the received second signal; and

  (iv) generating an output signal corresponding to a calibrated rate of a rotation of the mixer drum based on the calibration information.

39. Therefore, the Defendant’s prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 16 of the 468 Patent.

40. In addition, the Infringing Product comprises a gyroscopic rotational monitoring system wherein the particles are dry or in slurry, paste, or suspension. Therefore, the Defendant’s prototyping, making, testing, constructing, manufacturing, using, selling,

offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 17 of the 468 Patent.

41. The Infringing Product performs a concrete monitoring calibration using a processor-controlled system and a delivery mixer truck mixer drum according to a method comprising:

(a) (A) monitoring concrete provided in the mixer drum by measuring, while the concrete is in a state of equilibrium, the energy ("El") associated with rotating the concrete at a first constant speed ("V1") and energy ("E2") associated with rotating the concrete at a second constant speed ("V2") after a speed jump of plus or minus at least 2.5 rotations per minute (RPM);

(b) (B) calculating a slump value ("S") for the provided concrete based on El, V1, E2, and V2;

(c) (C) comparing El, V1, E2, V2, and S as calculated from step (B) with at least two data curves stored in processor-accessible memory, the stored data curves defining an E/V/S relationship for purposes of calculating slump across drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM, the at least two stored data curves comprising data obtained from previous deliveries of concrete when the previous concrete was in a state of equilibrium and comprising energy (E) values measured before and after at least 2.5 RPM jumps in constant drum speed (V) and slump values (S) as calculated from the previously stored E and V data, whereby the process-controlled system determines whether any of the at least two stored data curves match the El, V1, E2, V2, and S values of the provided concrete; and

(d) (D) monitoring the slump of the provided concrete in the mixer drum by calculating slump through measurement of the energy associated with rotating the concrete:

  (i) within 0.5 RPM - 6 RPM and within 6 RPM - 20 RPM drum speed ranges, based on one of the at least two stored data curves which is determined to constitute a match in step (C), and providing a visual indication that slump is being calculated by the system for drum speeds higher than 6 RPM; or

  (ii) within the 0.5 RPM - 6 RPM range only, if none of the stored curve data is determined to constitute a match in Step (C), and initiating an alert to a system operator or the truck driver, or dispatch center, that the system is active only for monitoring at drum speeds below 6 RPM.

42. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 1 of the 480 Patent.

43. In addition, the Infringing Product performs a concrete monitoring calibration according to a method wherein the equilibrium state of the concrete is confirmed by (i) averaging the energy associated with rotating concrete in the mixer drum at constant speed through each of at least two successive drum rotations and determining that the average

energy value does not vary over the at least two successive drum rotations, beyond a pre-established error margin value; or (ii) by confirming that an initial value of energy associated with rotation of the concrete in the drum at a given speed does not differ from the output at the end of a complete drum rotation, beyond a pre-established error margin value. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 2 of the 480 Patent.

44. In addition, the Infringing Product performs a concrete monitoring calibration according to a method wherein the mixer drum speed jump in step (A) is effectuated by an operator of the concrete delivery truck activating a mixer drum speed switch, dial, lever, or pushbutton (i) to increase mixer drum speed from 0.5 - 6 RPM to 6 - 20 RPM or to decrease drum speed from 6 - 20 RPM to 0.5 - 6 RPM; or (ii) to change drum speed by at least 2.5 RPM between two mixer drum speeds within the range of 0.5 - 20 RPM. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 3 of the 480 Patent.

45. In addition, the Infringing Product performs a concrete monitoring calibration according to a method wherein, in step (B), the slump (S) is calculated by:

(a) rotating the provided concrete in step (A) at a drum speed whereby S1 or S2 is within the range of 0.5-6 RPM, and employing at least one stored data curve defining an E/V/S relationship wherein the speed (V) is below 6 RPM; or

(b) establishing a linear relationship for El, V1, E2, and V2, which, if plotted as a function of drum speed (V) along a horizontal axis against energy (E) along a vertical axis, whereby the *slope* value of the line established by (El, V1) and (E2, V2) and *intercept* value of the line which intercepts the horizontal axis (E_0 at V = 0) are compared to a pre-established linear relationship of slope/intercept/slump (S) values as previously stored in controller-accessible memory.

46. Therefore, the Defendant’s prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 4 of the 480 Patent.

47. In addition, the Infringing Product performs a concrete monitoring calibration according to a method wherein El, V1, E2, and V2 obtained in step (A) are stored into memory. Therefore, the Defendant’s prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 5 of the 480 Patent.

48. In addition, the Infringing Product performs a concrete monitoring calibration according to a method wherein El, V1, E2, and V2 obtained in step (A) are stored into curve data among the at least two data curves in step (C). Therefore, the Defendant’s prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 6 of the 480 Patent.

49. In addition, the Infringing Product performs a concrete monitoring calibration according to a method wherein, in step (B), the slump calculation involves a change of speed

involving mixer drum speed into or out of the range of 0.5 RPM - 3.5 RPM. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 7 of the 480 Patent.

50. In addition, the Infringing Product performs a concrete monitoring calibration according to a method wherein, in step (C), the at least two stored data curves defining an E/V/S relationship for calculating slump across drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM, comprise data taken (i) from mixer drums on different concrete delivery trucks, (ii) from mixer drum speed jumps occurring at the delivery site before the concrete is poured into place at the site, or (iii) both (i) and (ii). Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 8 of the 480 Patent.

51. In addition, the Infringing Product performs a concrete monitoring calibration according to a method wherein, in step (C), the at least two stored data curves defining an E/V/S relationship for calculating slump across drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM, comprise data based on mixer drum speed jumps occurring at the delivery site before the concrete is poured. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 9 of the 480 Patent.

52. In addition, the Infringing Product performs a concrete monitoring calibration according to a method wherein, in step (C), at least six stored data curves define an E/V/S

relationship for calculating slump across drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM, and the data of said at least six stored data curves comprise at least 50 percent of drum speed jumps occurring at the delivery site before the concrete is poured. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 10 of the 480 Patent.

53. In addition, the Infringing Product performs a concrete monitoring calibration according to a method wherein, in step (C), the at least two stored data curves defining an E/V/S relationship for calculating slump across drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM is located in memory off of the delivery truck performing step (A). Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 11 of the 480 Patent.

54. In addition, the Infringing Product performs a concrete monitoring calibration according to a method further comprising downloading the at least two stored data curves defining an E/V/S relationship for calculating slump across drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM, from remote memory to controller-accessible memory located on the truck. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 12 of the 480 Patent.

55. In addition, the Infringing Product performs a concrete monitoring calibration according to a method wherein the measured energy (E) is measured using at least one

hydraulic pressure sensor effective for measuring the pressure associated with rotating the provided concrete in the mixer drum, or is measured using a force or stress gauge effective for measuring the force associated with moving the concrete within the rotating drum. Therefore, the Defendant’s prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 13 of the 480 Patent.

56. In addition, the Infringing Product performs a concrete monitoring calibration according to a method wherein at least one drum-mounted accelerometer, magnet, or rotary encoder is used to measure drum speed. Therefore, the Defendant’s prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 14 of the 480 Patent.

57. In addition, the Infringing Product performs a concrete monitoring calibration according to a method further comprising entering into controller-accessible memory ticket batch information corresponding to the provided concrete in step (A); determining whether any of the stored at least two data curves defining an E/V/S relationship for calculating slump across drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM in step (C) are pre-assigned to the entered ticket batch information; and verifying by performing steps (C) and (D)(i) to monitor the provided concrete and to confirm that the provided concrete conforms to the data curve pre-assigned to the entered ticket batch information. Therefore, the Defendant’s prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 15 of the 480 Patent.

58. In addition, the Infringing Product performs a concrete monitoring calibration according to a method further comprising determining that the provided concrete does not conform to the data curve pre-assigned to the entered ticket batch information, and employing step (C) to determine whether another stored data curve matches the provided concrete. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 16 of the 480 Patent.

59. In addition, the Infringing Product performs a concrete monitoring calibration according to a method further comprising the step of adjusting the slump of the concrete by introducing into the provided concrete an amount of water, chemical admixture, or mixture thereof, the amount introduced based on slump calculated using drum speed jumps between 0.5-6 RPM speed range and 6-20 RPM range. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 17 of the 480 Patent.

60. In addition, the Infringing Product performs a concrete monitoring calibration according to a method wherein, if a match is found in step (D)(i), the system processor adds El, V1, E2, and V2 data as obtained in step (A) into the matching curve data, and an alert is sent to the operator or user of the concrete monitoring system that the new data has been included in the stored curve data. Therefore, the Defendant's prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 18 of the 480 Patent.

61. The Infringing Product comprises a concrete monitoring system for monitoring concrete contained within a delivery mixer truck mixer drum, the system comprising a control processor to control the monitoring and configured to perform any one of the method as set out above in paragraphs 45-64. Therefore, the Defendant’s prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product as set out above infringes claim 19 of the 480 Patent.

62. The Defendant’s activities as described above constitute direct infringement of claims 1-17 of the 468 Patent and claims 1-19 of the 480 Patent in Canada. In particular, at least the Defendant’s past and ongoing commercial-based prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting in, from or to Canada of the Infringing Product as more particularly described herein constitutes a direct infringement of claims 1-17 of the 468 Patent and claims 1-19 of the 480 Patent.

63. Furthermore, the Defendant has induced infringement of claims 1-17 of the 468 Patent and claims 1-19 of the 480 Patent in Canada. Such inducement includes direct infringement by customers, distributors, sellers, offerors to sell, consumers and users of the Infringing Product, as particularized herein. The Defendant’s inducing activities include at least the direction, advertising, marketing, promotion, instruction and other support provided in connection with the commercial-based prototyping, making, testing, manufacturing, importing, exporting, selling, offering for sale, distributing and using within, from and to Canada by customers, distributors, sellers, offerors to sell, consumers and users of the Infringing Product.

64. The Defendant’s above-described influence over customers, distributors, sellers, offerors to sell, consumers and users to undertake the above-described infringing activities in Canada constitutes influence the Defendant knew would result in the infringing activities of others.

65. The Defendant’s activities described herein have deprived the Plaintiff of the full benefit of the subject matters claimed in the Verifi Patents. In particular, the Infringing Product performs and comprises the methods and systems claimed in the Verifi Patents, and the methods and systems claimed in the Verifi Patents are important to the Infringing Product and how it is made and used.

66. The Plaintiff is unaware of the full extent of the Defendant’s prototyping, making, testing, constructing, manufacturing, using, selling, offering for sale, distributing and exporting of the Infringing Product. Only the Defendant knows of the detailed particulars in respect of such infringing activities. However, the Plaintiff claims in respect of all such activities.

67. By reason of the Defendant’s actions described above, the Plaintiff has suffered, and stands to further suffer, loss and damage, and the Defendant has directly made profits and enjoyed commercial benefits and will continue to do so unless restrained by this Honourable Court, as specified above in paragraph 1. Such profits have been and will be made and enjoyed by the Defendant with respect to at least the above-mentioned sales of the Infringing Product, and with respect to other related benefits. Therefore, the Plaintiff claims damages or an accounting of profits that the Plaintiff may, after due inquiry, elect for infringement, and for inducing infringement, of the Verifi Patents.

68. The Plaintiff also claims under section 55(2) of the *Patent Act* reasonable compensation for damage the Plaintiff sustained by reason of the Defendant's activities after the applications for the 468 Patent and the 480 Patent became open to public inspection on May 21, 2015 and June 15, 2017, respectively, and before the grants of the 468 Patent and the 480 Patent on April 26, 2022 and March 28, 2023, respectively, that would have constituted an infringement of, or an inducement to infringe, the Verifi Patents had the 468 Patent and the 480 Patent been granted on May 21, 2015 and June 15, 2017, respectively.

69. This is not a simplified action under the *Federal Courts Rules*.

PLACE OF TRIAL

70. The Plaintiff proposes that this action be tried at Ottawa, Ontario.

DATED at Ottawa, Ontario on October 7, 2025.

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Schedule “A”

Canadian Patent No. 2,930,468

Innovation, Sciences et
Développement économique Canada
Office de la Propriété Intellectuelle du Canada

Innovation, Science and
Economic Development Canada
Canadian Intellectual Property Office

CA 2930468 C 2022/04/26

(11)(21) **2 930 468**

(12) **BREVET CANADIEN**
CANADIAN PATENT

(13) **C**

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(86) **Date de dépôt PCT/PCT Filing Date**: 2014/11/14
(87) **Date publication PCT/PCT Publication Date**: 2015/05/21
(45) **Date de délivrance/Issue Date**: 2022/04/26
(85) **Entrée phase nationale/National Entry**: 2016/05/11
(86) **N° demande PCT/PCT Application No.**: US 2014/065709
(87) **N° publication PCT/PCT Publication No.**: 2015/073825
(30) **Priorité/Priority**: 2013/11/15 (US61/904,680)

(51) **Cl.Int./Int.Cl.** *B28C 7/02* (2006.01),
B28C 5/42 (2006.01), *G01C 19/56* (2012.01),
G01P 3/00 (2006.01)

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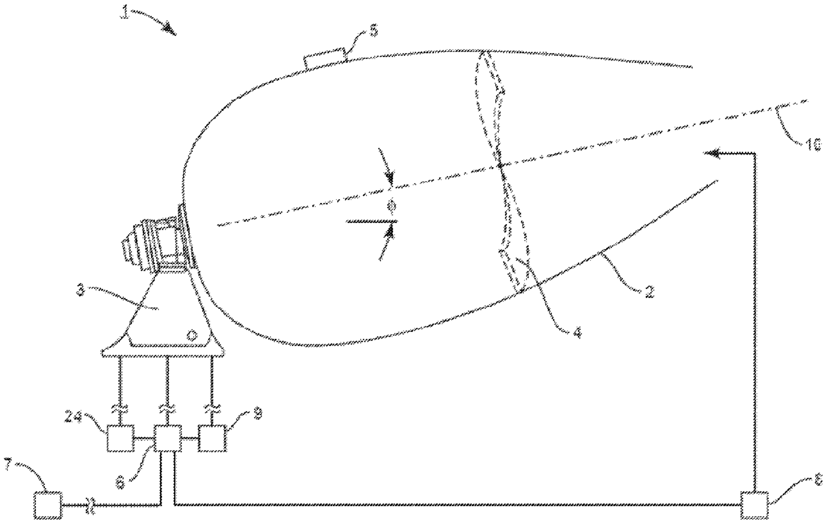
(54) **Titre** : DETERMINATION D'UNE ROTATION GYROSCOPIQUE
(54) **Title**: DETERMINATION OF GYROSCOPIC BASED ROTATION



(57) **Abrégé/Abstract**:
A gyroscopic rotational monitoring system may be utilized for monitoring one or more properties of rotatable container or vessel (2), and/or one or more properties of a displaceable material contained in the rotatable vessels. An exemplary aspect relates to the use of a gyroscope (22) and periodicity sensor (e.g., accelerometer) (24) to determine rotational speed of a concrete mixing drum, so that the slump or other property of the concrete can be monitored or adjusted such as by dosing with water, chemical admixtures, or mixture thereof.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
21 May 2015 (21.05.2015)

(10) International Publication Number
WO 2015/073825 A1

(51) International Patent Classification:
B28C 7/02 (2006.01) *G01C 19/56* (2012.01) *B01F 15/00* (2006.01) *G01P 3/00* (2006.01) *B28C 5/42* (2006.01)

(21) International Application Number: PCT/US2014/065709

(22) International Filing Date: 14 November 2014 (14.11.2014)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/904,680 15 November 2013 (15.11.2013) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) Title: GYROSCOPIC ROTATIONAL MONITORING SYSTEM

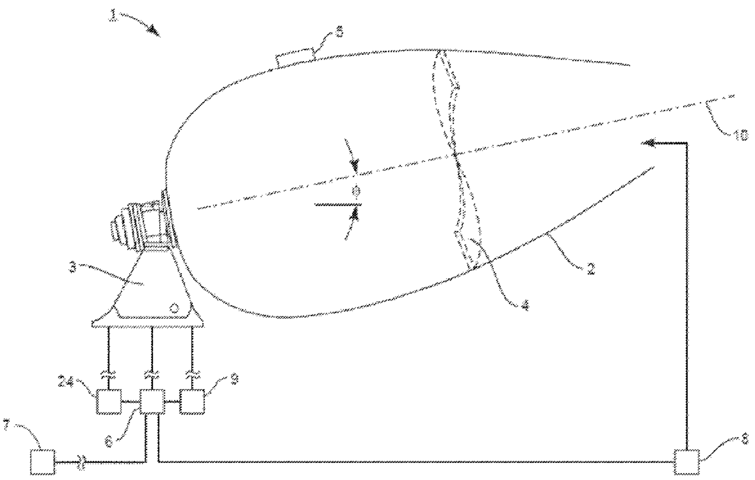


FIG. 1

(57) Abstract: A gyroscopic rotational monitoring system may be utilized for monitoring one or more properties of rotatable container or vessel (2), and/or one or more properties of a displaceable material contained in the rotatable vessels. An exemplary aspect relates to the use of a gyroscope (22) and periodicity sensor (e.g., accelerometer) (24) to determine rotational speed of a concrete mixing drum, so that the slump or other property of the concrete can be monitored or adjusted such as by dosing with water, chemical admixtures, or mixture thereof.

DETERMINATION OF GYROSCOPIC BASED ROTATION

[0001]

TECHNICAL FIELD

[0002] The present disclosure relates to manufacture and processing of hydratable cementitious compositions such as concrete, or other materials unrelated to cementitious compositions, and more particularly to a delivery system and method for monitoring one or more properties of a concrete, mortar, or other material contained in a rotating container.

BACKGROUND

[0003] Automated systems are used for mixing all types of materials, such as concrete mixes contained in ready-mix delivery trucks. Such automated systems measure the energy required for mixing a concrete load contained in a rotatable mixing drum thereby to ensure that "slump" values of the concrete (the term "slump" refers to the workability of a concrete mixture) during transport or at delivery are within a desired range. Such automated systems increase the reliability and consistency of the concrete during transportation and delivery by controlling the duration and rate of rotation of the mixing drum.

[0004] Once proper mixing of the concrete components is completed, it is important to maintain a minimum mixing drum speed to prevent segregation of components. This ensures even consistency as well as satisfactory strength in the concrete. On the other hand, it is important to avoid excessive drum speeds that would make the concrete overly stiff due to acceleration or advancement of the setting process, or due to deleterious breaking of air cells leading to release of entrained air from the concrete. Thus, automated slump monitoring systems require accurate measurement of the mixing drum speed.

[0005] In US Patent No. 5,752,768 to Assh, an automated mobile mixer system is described, which relies upon magnetic markers on the rotating mixing drum and magnetic detection sensors to measure the speed and direction of the drum. The drum speed is determined by measuring the time interval between the circumferentially spaced markers as they pass by the electro-magnetic sensors which are mounted on a non-rotating portion of the vehicle. (See e.g., US '768 at col. 9, line 62; col. 11, line 55; and Figs. 1 and 3).

[0006] The use of magnetic markers introduces inaccuracies for concrete monitoring systems. Current systems often employ approximately a dozen magnetic markers mounted circumferentially around the drum axis, as not every concrete mixer truck has bolt heads on the drum surface which can be configured for this purpose. In many cases, magnetic markers need to be attached using an adhesive to the outer drum surface. Further, where a sensor or marker is incorrectly placed or becomes dislodged or misaligned by a tree branch, washing brush, concrete material, or other objects, inaccuracies can be introduced into the sensing and measurement operations of the slump monitoring system.

[0007] For example, circumferential misalignment or uneven spacing between magnets, or an imbalance of individual magnet strengths among the markers, can introduce variations in speed readings perceived by the concrete slump monitoring system. For example, if magnets or sensors are weak, or the distance between them increases, it becomes difficult to detect the period peaks in the signal generated by the electro-magnetic sensors, and accuracy is lost. A missing magnet can have an even more severe impact on drum speed monitoring.

[0008] In US Patent No. 8,118,473 and WO 2012/024393 A1 to Compton et al. (both owned by the common assignee hereof), magnetic sensing, as well as wireless accelerometers mounted on the concrete mixing drum, are disclosed for measuring drum speed. In addition to using magnetic sensors, one could also measure "ticks of the speed sensor built into the motor (used for rotating the drum)" or could detect signals generated by "an auxiliary processor coupled to a wireless accelerometer" mounted on the mixing drum. (US '473 at col. 21, line 65).

[0009] However, while a wireless accelerometer mounted on the concrete drum might be sufficient for speed measurement when the delivery truck is parked or otherwise stationary, large errors can be introduced when the truck is in motion. Inaccuracies can be introduced, for example, when the truck is accelerating, braking, turning hard, or travelling on non-level roads or irregular terrain.

[0010] Concrete mixing drums, as seen on ready-mix delivery trucks on the roads today, are not pure cylinders that rotate in a purely parallel or perpendicular direction with respect to the ground. Rather, such mixing drums have an irregular pear-like shape, with angled inner walls upon which are mounted two or more blades spirally-oriented around the drum rotational axis, which is slanted 10-20 degrees with respect to horizontal ground; and the concrete is pushed (downwards at a slant) towards a more bulbous end when the drum is rotated in one direction; or otherwise discharged (upwards at a slant) towards and through the drum opening located at the other (less bulbous) end when the drum is rotated in the opposite direction.

SUMMARY

[0011] As described herein, a gyroscope may be utilized in determining rotational speed of a structure, such as a rotating vessel, a container of displaceable materials or fluids, or the like.

[0012] According to an aspect of the present disclosure, there is provided a system comprising: a gyroscope coupled to a rotatable concrete mixer drum having spirally-mounted mixer blades and an axis of rotation, the gyroscope for providing a first signal corresponding to a rate of rotation of the mixer drum; a periodicity sensor coupled to the rotatable concrete mixer drum, the periodicity sensor for providing a second signal corresponding to a period of rotation of the concrete mixer drum; a processor; and memory coupled to the processor, the memory comprising executable instructions that when executed by the processor cause the processor to effectuate operation of the concrete mixer drum having the spirally-mounted mixer blades, whereby rotation of the mixer drum in a first direction causes contents of the drum to be mixed, and whereby rotation of the mixer drum in a second direction opposite the first direction causes the contents of the drum to be expelled from the drum, the instructions executable by the processor comprising: receiving the first signal; receiving the second signal; determining calibration information based on the received first signal and the received second signal; and generating an output signal corresponding to a calibrated rate of a rotation of the concrete mixer drum based on the calibration information.

[0012a] According to another aspect of the present disclosure, there is provided a system comprising: a gyroscope coupled to a rotatable mixer drum having spirally-mounted mixer blades and an axis of rotation, the gyroscope for providing a first signal corresponding to a rate of rotation of the mixer drum, the mixer drum being effective for mixing a displaceable material chosen from powders, particles, grains and seeds, cereals, coffee, detergents, pharmaceutical materials, and concrete; a periodicity sensor coupled to the rotatable mixer drum, the periodicity sensor for providing a second signal corresponding to a period of rotation of the mixer drum; a processor; and memory coupled to the processor, the memory comprising executable instructions that when executed by the processor cause the processor to effectuate operation of the mixer drum having the spirally-mounted mixer blades, whereby rotation of the mixer drum in a first direction causes contents of the drum to be mixed, and whereby rotation of the mixer drum in a second direction opposite the first direction causes the contents of the drum to be expelled from the drum, the instructions executable by the processor comprising: receiving the first signal; receiving the second signal; determining calibration information based on the received first signal and the received second signal; and generating an output signal corresponding to a calibrated rate of a rotation of the mixer drum based on the calibration information.

[0013] The present disclosure discloses a device comprising a rotatable container or vessel having a wall for containing a displaceable material; a gyroscope which provides an output signal in response to the rotating state of the container or vessel, the gyroscope being connected, electrically or wirelessly, to a processor unit programmed for determining rotational speed of the container or vessel in response to the gyroscope output signal.

[0013a] The terms "container" and "vessel" are used herein to refer to objects that can contain displaceable materials, and includes drums or other enclosures. The term "displaceable materials" includes powders, particles (e.g., dry or in slurry, paste, or suspension), grains and seeds, cereals, coffee, detergents, pharmaceutical materials, concrete, and the like.

[0014] In an exemplary configuration, the present disclosure provides a concrete monitoring system wherein a gyroscope is employed for determining rotational speed of a concrete mixing drum, and wherein an accelerometer (or other timing device) is optionally used for the purpose of calibrating and maintaining the accuracy of the gyroscope. Enhanced accuracy in the monitoring of the mixing drum speed in turn enhances the performance of automated systems used for monitoring concrete that is transported in ready-mix delivery trucks.

[0015] Gyroscopic-based rotation determination, as described herein, may, for example, be suited for accurately measuring the rotational speed of containers or vessels that are subject to changes in tilt angles or other irregularities and variations in the environment that could otherwise affect accuracy of speed measurement. The use of a gyroscope with an optional accelerometer may be useful for monitoring rotational speed of various kinds of containers or vessels, such as, for example, food mixing machines, and washer and dryer units for clothes and fabrics, or the like, wherein the load is displaced (moved around) by rotational movement of the drum or vessel, and the displaced load contained within the drum itself can create unbalance to the rotational axis, moment, or angular disposition of the drum or vessel; and a processing unit can be programmed in response to the signals generated by the gyroscope to adjust or to correct the unbalanced condition by altering energy being fed to the motor which drives rotation of the drum or vessel.

[0016] The use of a gyroscope may be advantageous in situations wherein it may be desirable to monitor rotational speed numerous times within a single rotation of the container or vessel.

[0017] In an exemplary configuration, the present disclosure provides a wireless gyroscope/accelerometer device that can be installed in each wheel-and-tire assembly on a passenger car, racing car, truck, or other vehicle which uses tires containing air or other materials, and by using an onboard or remote computer processor programmed to monitor speed at various points within single tire rotations, it can be determined whether a particular wheel/tire assembly on the car requires dynamic balancing and/or re-alignment, and a signal or diagnosis can be displayed on a handheld or dashboard device or other form of on-board monitoring system.

[0018] As another example, a wireless gyroscope/accelerometer assembly can be mounted on the outer belly of concrete mixing drums to monitor rotational drum speed at a frequency greater than the number of magnetic markers that could otherwise be attached to the outer mixing drum.

[0019] In the racing car and concrete truck examples, to name a few, the use of an accelerometer can be used to calibrate the gyroscope, which is susceptible to drift due to temperature and other environmental factors.

[0020] Thus, an exemplary gyroscopic monitoring system of the present disclosure for measuring a rotational rate of a rotatable vessel configured to contain a displaceable material comprises: a gyroscope for connection to the rotatable vessel during operation of the rotatable vessel, the gyroscope providing an output signal corresponding to an angular velocity of the rotatable vessel; at least one periodicity sensor for connection to the rotatable vessel during operation of the rotatable vessel, the at least one periodicity sensor providing an output signal corresponding to a period of rotation of the rotatable vessel; a processor configured to receive the output signal from the gyroscope and the output signal from the at least one periodicity sensor, and further configured to provide: an output signal corresponding to the rotational rate of the rotatable vessel; and calibration information based on the output signal from the gyroscope and the output signal from the at least one periodicity sensor.

[0021] In an aspect of the disclosure, the gyroscope is a micro-electro-mechanical system. In another aspect, the at least one periodicity sensor is an accelerometer. The gyroscope and accelerometer may be coupled to the processor as well as to battery or power pack and wireless transmitter for mounting on a concrete mixing drum or other rotating vessel containing a displaceable material.

[0022] In still further exemplaryconfigurations, the present disclosure provides a rotatable concrete mixing vessel having a monitoring system for measuring the rotational rate of the rotatable concrete mixing vessel, comprising: a gyroscope for connection to the rotatable vessel during operation of the rotatable vessel, the gyroscope providing an output signal corresponding to an angular velocity of the rotatable vessel; at least one periodicity sensor for connection to the rotatable vessel during operation of the rotatable vessel, the at least one periodicity sensor providing an output signal corresponding to a period of rotation of the rotatable vessel; a processor configured to receive the output signal from the gyroscope and the output signal from the at least one periodicity sensor, and further configured to provide: an output signal corresponding to the rotational rate of the rotatable vessel; and calibration information based on the output signal from the gyroscope and the output signal from the at least one periodicity sensor.

[0023] In still further exemplary configurations which include a slump monitoring system, the slump monitoring system comprises: a second processor, the second processor configured to receive the output signal corresponding to the rotational rate provided by the processor; and an energy sensor operably connected to the second processor, the energy sensor measuring the energy required to rotate the rotatable vessel.

[0024] Further advantages and features of the present disclosure are described in further detail hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] An appreciation of the benefits and features of the present disclosure may be more readily comprehended by considering the following written description of different aspects in conjunction with the drawings, wherein:

[0026] FIG. 1 is a diagrammatic illustration of an example rotational monitoring unit mounted on a rotatable concrete mixing drum of a delivery truck and used in combination with (or alternatively, as part of an automated slump monitoring system).

[0027] FIG. 2A is a schematic depiction of an exemplary gyroscopic rotational measuring device of the present disclosure.

[0028] FIG. 2B is a schematic depiction of another example gyroscopic rotational measuring device.

[0029] FIG. 3A is a graph illustrating example data from an accelerometer that is mounted onto a rotating vessel.

[0030] FIG. 3B is a graph illustrating example data from a hydraulic sensor measuring the torque of a motor driving a rotating vessel.

[0031] FIG. 4A is an example graphic depiction of drum speed including uncorrected gyroscope speed, accelerometer speed, and magnet speed;

[0032] FIG. 4B is an example graphic depiction of drum speed including corrected gyroscope speed, accelerometer speed, and magnet speed.

[0033] FIG. 5 is a schematic depiction of an exemplary slump monitoring system.

[0034] FIG. 6 is a block diagram of an example apparatus that me by utilized to facilitate gyroscopic rotation.

[0035] FIG. 7 shows a flow diagram of an example process for facilitating a determination of gyroscopic rotation.

DETAILED DESCRIPTION

[0036] The present disclosure now will be described more fully hereinafter with reference to the accompanying drawings, in which various exemplary configurations are shown illustrating variations within the scope of the disclosure. This disclosure may, however, be embodied in many different forms and should not be construed as limited to the configurations set forth herein; rather, these configurations are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the disclosure to those of ordinary skill in the art.

[0037] FIG. 1 is an illustration of an example mixing system 1 comprising a rotatable drum 2 drivable by a motor (e.g., hydraulic pressure or electric drive) 3. In concrete mixing systems for example, such as the systems used on concrete ready-mix delivery trucks, during standard operation, the drive 3 and drum 2 may be configured to cause the drum 2 to rotate in a first direction, causing the contents of the drum to be mixed, or in a second direction opposite the first direction, with spirally-mounted blades 4 or paddles causing the contents of the drum to discharge out of the mixing drum 2. The term “standard operation,” as used herein, refers to operation of the rotatable vessel, such as the drum 2, when the vessel is being used for its regularly intended purpose, such as mixing and delivering concrete, versus other operational uses, such as a calibration mode that may be utilized to calibrate the gyroscope on the rotatable vessel prior to standard operation or, as another example, during intervals wherein the truck is stationary.

[0038] An exemplary mixing system 1 may comprise a rotational monitoring unit 5, such as a gyroscopic rotational measuring device, for example, to measure the rotation of the drum 2. In a further exemplary configuration, the rotational monitoring unit 5 may be mounted directly onto the drum 2. The unit 5 may also be mounted, such as by adhering or fastening, in or on a rotatable vessel or container at a location which is not coincidental with its rotational axis 10. The drum 2 may be mounted an any appropriate angle, ϕ, as depicted in Fig. 1. In an example configuration, the unit 5 may be mounted at a distance from its rotational axis 10; wherein greater accuracy may be provided by larger distances from the rotational axis 10 of the rotatable drum 2. As the drum 2 is driven by the motor 3, the drum rotates about the rotational axis 10, which may be offset by an angle ϕ relative to the ground, and the monitoring unit 5 measures the angular velocity of the drum 2. The rotation of the drum 2 about axis 10 may be uniform, for example, about the geometric centerline of the drum 2. The monitoring unit 5 is configured to provide an output signal corresponding to the measured angular velocity.

[0039] As further illustrated in FIG. 1, an exemplary concrete monitoring system of the disclosure may comprise one or more processor units 6 which may be electrically or wirelessly connected to receive signals from the motor or hydraulic pressure drive 3 as well as to control the speed of the motor/drive 3. The processor unit 6 may be electrically or electronically connected to one or more memory locations 7, which may be used for storing program applications for monitoring and controlling the motor or hydraulic pressure drive 3 (thereby adjusting the speed of rotation of the drum 2), and the processor unit 6 is electrically connected or electronically connected to one or more dispensing systems 8 for administering water, chemical admixtures, or both into a concrete mix contained in the mixing drum 2. In an example configuration, the processor unit 6 may be coupled to the memory location(s) 7, and memory location(s) 7 may comprise a processor-readable medium storage medium (also referred to as a computer-readable storage medium, machine-readable storage medium, etc.) comprising executable instructions that when executed by processor unit 6, may cause processor unit 6 to effectuate operations for gyroscopic-based rotation determination as described herein.

[0040] As is to be understood, a storage medium (*e.g.*, a computer-readable storage medium, a machine-readable storage medium, a processor-readable storage, etc.) has a concrete, tangible, physical structure. As is known, a signal does not have a concrete, tangible, physical structure. The one or more memory locations 7, as well as any storage medium described herein, is not to be construed as a signal. The one or more memory locations 7, as well as any storage medium described herein, is not to be construed as a transient signal. Further, the one or more memory locations 7, as well as any storage medium described herein, is not to be construed as a propagating signal. The one or more memory locations 7, as well as any storage medium described herein, is to be construed as an article of manufacture having a concrete, tangible, physical structure.

[0041] Concrete monitoring systems involving measurements of the energy (*e.g.*, hydraulic pressure) required to rotate the mixing drum, using a concrete monitoring processor 6, and adjusting the concrete mix by administering water and/or chemical admixtures, are commercially available from Verifi, LLC, of Ohio and Cambridge Massachusetts. Automated concrete monitoring systems are variously disclosed in patent literature, some of which was authored by Verifi LLC, including US Pat. No. 8,118,473 to Compton et al.; US Pat. No. 8,020,431 to Cooley et al.; US Pat. No. 8,491,717 to Koehler et al.; US Serial No. 10/599,130 to Cooley et al. (Publ. No. US 2007/70185636 A1); US Serial No. 11/834,002 to Sostaric et al. (Publ. No. US 2009/0037026 A1); and US Serial No. 258,103 to Koehler et al. (Publ. No. 2012/0016523 A1).

[0042] For example, in US 8,491,717 of Koehler et al. the monitoring system can track dosages of polycarboxylate ether cement dispersants and air control agents (air entraining and/or detraining agents) based on nominal dosage profiles which are stored in memory.

[0043] As generally illustrated in FIG. 1 and more specifically illustrated in FIGS. 2A and 2B, a rotational monitoring unit 5 may be configured to provide an output signal corresponding to a calibrated angular velocity. A wireless transmitter may transmit signals to one or more processor units 6, which may also receive signals from the energy sensor 9 which monitors energy (*e.g.*, hydraulic) required to rotate a vessel, such as, for example, a mixing drum containing a load of concrete. The processor unit 6 may be programmed to monitor slump and/or other properties of the concrete load, and/or to adjust slump and/or other properties of the concrete by administering a liquid, such as, for example, water, chemical admixture, or both into the concrete. The processor unit 6 may be programmed to transmit the data corresponding to the various electrical inputs to another computer processor located at a remote location. Chemical admixtures may be added to concrete for purposes of modifying any number of properties, including, by way of example, reducing the need for water (*e.g.*, plasticizing, increasing workability), controlling the setting of concrete (e.g., set accelerating, set retarding), managing air content and quality (*e.g.*, air entrainers, air detrainers), shrinkage reduction, corrosion inhibition, and other properties.

[0044] Greater details of the monitoring unit of FIG. 1 and the monitoring system are provided with reference to FIG. 2A, which includes a schematic depiction of a configuration of a rotational monitoring unit 5 including a gyroscope 22. In this particular configuration, the rotational monitoring unit 5 may be a wireless sensor unit 20. The wireless sensor unit 20 may comprise a gyroscope 22, a periodicity sensor 24, an embedded microprocessor 26, and a wireless transmitter 32. The embedded microprocessor 26 may be programmed for data collection 28. A periodicity sensor, or sensors, 24 may be positioned at any appropriate location of locations on the drum 2. For example, a periodicity sensor(s) 24 may be positioned within monitoring unit 5. In an example configuration, the gyroscope, or gyroscopes, 22 and the periodicity sensor(s) 24 may be incorporated into a common circuit.

[0045] The gyroscope 22 may provide an output signal corresponding to the angular velocity of the rotating mixing drum 2 and the periodicity sensor 24 may provide an output signal corresponding to the period of rotation of the mixing drum 2. The embedded microprocessor 26 may be configured to receive the output signal from the gyroscope 22 and to receive the output signal from the periodicity sensor 24 and process the output signals for transmission as received data. In a further exemplary configuration, there may be more than one periodicity sensor 24. The embedded microprocessor 26 may send the received data to an external embedded processor 6 (such as the processor that monitors the energy or hydraulic pressure required to rotate the mixing drum and to control the rotational speed of the drum), or to a processor that may not be located on the mixing truck. In an aspect, the data is sent by a wireless transmitter 32 which is coupled to the sensor unit 20 and transmits the data to a wireless receiver 34 in communication with an embedded microprocessor 6 that monitors and controls the energy for rotating the mixing drum. The embedded microprocessor 6 comprises logic, such as an algorithm 30, for calibration of the gyroscope 22 based on the received data. The embedded processor 6 provides an output signal corresponding to the rotational rate of the drum 2 and provides calibration information 38 based on the output signals from the gyroscope 22 and the periodicity sensor 24.

[0046] In another configuration, the wireless sensor unit 20, comprising the gyroscope 22 is located on a rotating vessel which contains a displaceable material. During operation, the rotating vessel rotates about an axis. The rotating vessel could be a rotating wheel, (clothes) dryer, (clothes) washer, or other rotating object which contains a displaceable material, such as, for example, concrete, cement mortar, fabric or clothes, food or food components, pharmaceuticals, and fluid materials (such as pastes, slurries, or particles and suspensions, gases or other flowable materials). The wireless sensor unit 20 provides an angular velocity to a processor 6 which calibrates the rotational speed.

[0047] As another example, a wireless sensor unit 20 can be placed in the wheels/tires of a transportation vehicle to transmit data about each wheel/tire combination to an embedded microprocessor in the vehicle or at a remote location.

[0048] In further exemplary configurations, a temperature sensing device or other calorimetric device could also be included in the wireless sensor unit 20, which would be useful for the wheels/tires situation as well as for concrete mixing drums (as it is helpful to know the temperature of the concrete mix contained in the drum).

[0049] Referring to FIG. 2B, a schematic depiction of another configuration of a gyroscopic rotational monitoring unit is shown. In this particular configuration, the rotational monitoring unit is also a wireless sensor unit 20. The wireless sensor unit 20 comprises a gyroscope 22, a periodicity sensor 24, an embedded microprocessor 26, and a wireless transmitter 32. The embedded microprocessor 26 comprises a function for data collection 28 as well as an algorithm 30 for calibration.

[0050] In this configuration, the gyroscope 22 may provide an output signal corresponding to the angular velocity of the rotating mixing drum 2 and the periodicity sensor 24 provides an output signal corresponding to the period of rotation of the mixing drum 2. The embedded microprocessor 28 is configured to receive the output signal from the gyroscope 22 and to receive the output signal from the periodicity sensor 24. The embedded microprocessor 26 comprises an algorithm 30 for calibration. The embedded processor 26 provides an output signal corresponding to the rotational rate of the drum 2 and provides calibration information 38 based on the output signals from the gyroscope 22 and the periodicity sensor 24. The embedded microprocessor 26 sends the received data to an external embedded microprocessor 6, the external embedded processor 6 may or may not be located on the mixing drum 2 or non-rotating portion of the mount or platform for the mixing drum. The received data is sent by a wireless transmitter 32 transmitting the data to a wireless receiver 34.

[0051] It will be understood that the wireless sensor unit (20) configurations diagramed in FIG. 2A and 2B will further comprise self-contained power supplies, such as batteries or battery packs, for powering the operation of the microprocessor 26, gyroscope 22, accelerometer 24 (or other periodicity sensor used within the unit), and other components. In further exemplary configurations, a motion detection device or system connected to a motion switch can be used to shut off power to conserve energy of the batteries or power pack in the wireless sensor unit 20. For example, the embedded processor 6 which monitors energy for turning the mixing drum 2 can sense that absence of motion and send a signal to a switch or the other microprocessor 26 to shut down the gyroscope 22 and accelerometer 24 and other components, so as to prolong battery life; and upon detecting pressure, the processor 6 can be programmed to send a signal to the switch or the other processor 26 in the wireless (gyroscope-containing) wireless sensor unit 20 to resume the flow of power to the gyroscope and other components as needed.

[0052] A “gyroscope”, as used herein, refers to a device for measuring movement about a rotational axis and for generating other useful information. Different types of gyroscopes include (non-exhaustive) solid-state gyroscopes, Micro-Electro Mechanical System (MEMS) gyroscopes, laser gyroscopes, and fiber optic gyroscopes. Traditionally, gyroscopes have been used to provide stability or maintain a reference direction in navigation systems. These systems tend to operate in the 0 to 360 degree range. Gyroscopes have a tendency to drift based on physical properties, such as mass, inertia, and friction, as well as environmental factors such as temperature. When a gyroscope drifts, an offset is created between the actual movement about a rotational axis and the measured movement. Periodic calibration of the gyroscope can correct for such drift. Any gyroscope may be utilized in configurations.

[0053] The term “periodicity sensor” as used herein refers to an electrical or electronic sensor device that detects, senses, or otherwise monitors the rotation angle of a rotatable vessel or container. The periodicity sensor is used to provide information from which the rotational position of the rotatable vessel can be calculated and utilized to determine the period of rotation. The period of rotation is defined as being the time required for one complete revolution of the rotatable vessel.

[0054] In an aspect, the periodicity sensor 24 can be an accelerometer. The accelerometer may be a one-axis, two-axis, or three-axis accelerometer, which measures the acceleration of a rotatable vessel. The accelerometer is operably connected to the rotatable vessel, and may be mounted on the outside of a rotating vessel and used to measure the acceleration at the location where it is mounted. For a continuously rotating vessel, the accelerometer will provide a repetitive oscillation as the mounted accelerometer moves around the rotational axis of the vessel or mixing drum 2. As further discussed below, other forms of periodicity sensors may be utilized, including sensors that are not mounted to the rotating vessel.

[0055] Referring to FIG. 3A, the graph illustrates data from an accelerometer that is mounted onto a rotating vessel (e.g., mixing drum). Each individual point (square) 40 plotted illustrates data measured by the accelerometer while the vessel rotates. The solid line 42 illustrates a smooth signal created by low pass filtering of the individual points. The distance from peak to peak of solid line 42 is one rotation, as illustrated by the maximum peaks at 44. The distance from the valley to valley of solid line 42 is one rotation, as illustrated by the minimum valleys at 46. The detected rotation maxima 44 and rotation minima 46 are inherent properties of the rotating vessel and provide information regarding the periodicity of the vessel. A relatively smooth line 42 with consistent rotation maximums or minimums would indicate that the rotating vessel is operating at a stable rate.

[0056] In still a further aspect of this disclosure, the gyroscope and an accelerometer are both coupled to a processor and a transmitter to form a rotational monitoring unit, as diagrammatically illustrated above. This rotational monitoring unit 5 can be housed in a protective housing unit that can be mounted onto a rotatable vessel, such as mixing drum 2. This rotational monitoring unit can also be mounted on other rotatable vessels including a washer or dryer drum, or other rotating vessels.

[0057] In a still further exemplary configuration, the gyroscope and a periodicity sensor may both be coupled to a processor and a transmitter as shown in FIG. 2B, but only the gyroscope is mounted onto the rotatable vessel, while the periodicity sensor is not mounted onto the rotating vessel. In this configuration, the periodicity sensor may be located elsewhere on the vehicle or device operating the rotatable vessel, as further described below. However, the periodicity sensor is still operably connected to the rotating vessel via a wireless transmitter or similar means of communication, in order to measure the period of rotation.

[0058] As noted above, the periodicity sensor need not be an accelerometer and need not be mounted onto the rotatable vessel, such as illustrated in FIG. 3B, in which the periodicity sensor can be a hydraulic pressure sensor. A hydraulic pressure sensor measures the amount of energy required to move the vessel by monitoring hydraulic fluid lines of the motor 3. The graph illustrates measured pressure data from a hydraulic sensor measuring the energy for driving a rotating vessel. The individual circles 50 represent data corresponding to energy as measured by the hydraulic pressure sensor and line 52 connects the individual data points 50. The distance from peak to peak of solid line 52 is one rotation maximum 54. The distance from the valley to valley of solid line 52 is one rotation minimum 56. The detected rotation maxima 54 and rotation minima 56 are inherent properties of the rotating vessel and provide information regarding the periodicity of the vessel. A relatively smooth line 52 with consistent rotation maximums or minimums would indicate that the rotating vessel is operating at a stable rate.

[0059] In still further exemplary configurations of the present disclosure, the rotational rate measured by the gyroscope may be calibrated by subjecting the output signals generated by the periodicity sensor (e.g., accelerometer) to a low pass filter, such as a Butterworth, 5th order low-pass with a relative cut-off frequency of 0.1 * Nyquist. The minimum and maximum values of the filtered data are obtained, and from these values, the rotational rate or speed may be determined. In an aspect, the measured speed of the drum should be stable before the system begins to calibrate the gyroscope. The measured rotational speed, for example, may be unstable when a mixing drum is mounted onto a moving truck and affected or influenced by the various movements of the truck, e.g., stopping, turning, driving up or down ramps or over potholes, bumps, etc. To determine the stability of either a periodicity sensor or gyroscope, a Median Absolute Deviation (MAD) is used over a window of previous measurements. If the MAD over the window is less than a predetermined threshold value, then the output signals are considered stable. When the output signals are considered stable, a calibration constant may be computed by taking the median values of the output signals over the measurement windows to obtain linear averages of the two signals; one linear average is divided by the other to obtain the calibration constant. The calibration constant is then applied to the gyroscope output signal to calibrate the signal to better represent the actual rotation. In an aspect, calibration constants may be determined while the drum is rotating at different speeds. This ensures the best understanding of how the devices perform in particular circumstances.

[0060] Different calibration methods could be used depending on the requirements of the particular devices used. For concrete mixer drum applications, where typical rotation speeds are 1-20 revolutions per minute (RPM), an exemplary mode or method of calibration would involve the aforementioned linear-to-linear calibration.

[0061] In other configurations, a gyroscope or accelerometer which does not have linear response, the calibration could require an adaptive procedure involving multiple samples taken across the operational range of vessel rotation speed for the devices in actual application.

[0062] Referring to FIG. 4A, a graphic depiction of drum speed of a rotating mixing drum according to a number of different measuring devices is illustrated. The units for drum speed are revolutions per minute (RPM). The graph shows three sets of data all measured over the period of approximately 300 seconds (6000 seconds to 6300 seconds). Line 64 illustrates drum speed measurements using magnetic sensors mounted to the drum. Line 62 illustrates drum speed measurements for an accelerometer mounted to the drum. Line 60 illustrates drum speed measurements for an uncalibrated gyroscope mounted to the drum. As illustrated by the graph, the lines 64 and 60 for the drum speeds measured by the magnetic sensors and the gyroscope are similar in shape, but often indicate different speeds, while the line 62 for the drum speed data as derived through the use of the accelerometer illustrates irregular behavior which may have been caused by changes in speed of the drum, movements of the truck carrying the drum, etc.

[0063] FIG. 4B is similar to FIG. 4A, in that lines 74, 72, and 70 each illustrate drum speed measurements for magnetic sensors, an accelerometer, and a gyroscope, respectively, but unlike FIG. 4, the gyroscope drum speed measure 70 has been corrected based on periodicity data, as disclosed herein, and now rather precisely tracks the magnetic drum speed 74.

[0064] As illustrated in FIG. 1, in another configuration, a system and method utilize the calibrated rotational rate of the rotatable vessel for monitoring and/or controlling the slump (or other rheological property) of a concrete, mortar, or other hydratable cementitious mix contained in a rotatable concrete mixing drum 2, and is particularly suited for mixing drums on ready-mix concrete delivery trucks.

[0065] In configurations pertaining to the monitoring and/or control of concrete and other hydratable cementitious materials, the following definitions shall apply:

- The term “cement” as used herein includes hydratable cement such as Portland cement which is produced by pulverizing clinker consisting of hydraulic calcium silicates, aluminates and aluminoferrites, and one or more forms of calcium sulfate (e.g., gypsum) as an interground additive. Typically, Portland cement is combined with one or more supplemental cementitious materials, such as fly ash, granulated blast furnace slag, limestone, natural pozzolans, or mixtures thereof, and provided as a blend. Thus, the term “cement” may also include supplemental cementitious materials which have been inter-ground with Portland cement during manufacture.
- The term “cementitious” may be used herein to refer to materials that comprise Portland cement or which otherwise function as a binder to hold together fine aggregates (e.g., sand), coarse aggregates (e.g., crushed gravel), or mixtures thereof, in concrete and mortar.
- The term “hydratable” as used herein refers to cement or cementitious materials that are hardened by chemical interaction with water. Portland cement clinker is a partially fused mass primarily composed of hydratable calcium silicates. The calcium silicates are essentially a mixture of tricalcium silicate ($3CaO\cdot SiO2$ or “C3S" in cement

chemists' notation) and dicalcium silicate ($2CaO\bullet SiO_2$, "C2S") in which the former is the dominant form, with lesser amounts of tricalcium aluminate ($3CaO\bullet Al_2O_3$, "C3A") and tetracalcium aluminoferrite ($4CaO\bullet Al_2O_3\bullet Fe_2O_3$, "C4AF"). (See e.g., Dodson, Vance H., Concrete Admixtures (Van Nostrand Reinhold, New York, NY 1990), page 1.).

- The term "concrete" is used herein generally to refer to hydratable cementitious mixtures comprising cement, sand, and usually a coarse aggregate such as crushed stone or gravel, and optionally a chemical admixture such as one or more chemical admixtures (e.g., one or more PCEs).

[0066] A slump monitoring system comprises an energy sensor for monitoring the energy needed for rotating a concrete mixing drum for containing a hydratable cementitious mix, such as concrete, and a rotational measuring device mounted on the concrete mixing drum for measuring the rotational speed of the drum.

[0067] Referring to FIG. 5, an example schematic depiction of a slump monitoring system operating in conjunction with a rotational measuring system is illustrated. In this particular configuration, the rotational measuring device is a wireless sensor unit 20 which comprises a gyroscope 22, a periodicity sensor 24, an embedded processor 26, and a wireless transmitter 32. The embedded microprocessor 26 comprises a function for data collection 28 as well as an algorithm 30 for calibration. In an configuration, the algorithm 30 for calibration may be located within another processor external to the wireless sensor unit 20. The slump monitoring system further comprises a wireless receiver 34, an external embedded processor 6, and an energy sensor 9. The external embedded processor 6 may or may not be located on the concrete mixing drum 2.

[0068] In this configuration, the wireless sensor unit 20 is configured to be operably connected to a rotatable vessel, such as a concrete mixing drum. The gyroscope 22 provides an output signal corresponding to the angular velocity of the rotating concrete mixing drum 2 and the periodicity sensor 24 provides an output signal which is used by the microprocessor 26 for calculating the period of rotation of the concrete mixing drum 2. The embedded microprocessor 26 is configured to receive the output signal from the gyroscope 22 and to receive the output signal from the periodicity sensor 24. The embedded microprocessor 26 is programmed to apply an algorithm 30 for calibration. The embedded processor 26 provides an output signal corresponding to the rotational rate of the concrete drum 2 and provides calibration information 38 based on the output signals from the gyroscope 22 and the periodicity sensor 24. The embedded microprocessor 26 may or may not be located on the same platform or structure on which the rotatable drum is mounted. The output signal from the embedded microprocessor 26 is sent by a wireless transmitter 32 transmitting the data to a wireless receiver 34.

[0069] The energy sensor 9 can be operably connected to a motor or hydraulic pressure drive 3. The energy sensor 9 may also be mounted onto the motor 3. The wireless sensor unit 20 can be operably connected to a concrete mixing drum. In an configuration, the wireless sensor unit 20 is mounted onto the concrete mixing drum.

[0070] The gyroscope rotational measuring device 5 can be sold and used as part of an automated concrete slump monitoring system for monitoring and adjusting concrete slump. Such automated slump monitoring systems which are contemplated for use with or as part of the present disclosure are commercially available from Verifi LLC, 9466 Meridian Way, West Chester, Ohio USA.

[0071] If the microprocessor 6 is programmed to monitor and to adjust slump or other properties, it may be coupled and/or wirelessly connected to an accessible memory unit or units, either onboard the truck or located at a remote location. The memory units may contain data for correlating admixture amounts to slump effects or other properties of the concrete (slump shall be used as a shorthand example herein), whereby current slump can be adjusted to or towards a target slump.

[0072] In further exemplary configurations, gyroscope-containing wireless sensor unit 20, as illustrated in FIG. 2A, may contain an embedded processor, which, in addition to being programmed to calculate rotational speed of the drum, may be programmed to determine the number of mixing drum revolutions occurring in a period of time, the direction of the drum rotation, or both. In still further configurations, the processor 26 may be programmed to control and monitor the energy required by the motor or hydraulic drive unit to rotate the mixing drum (or a separate processor can be contained in the wireless sensor unit 20 for this purpose). A processor located in the wireless sensor unit 20 may be used to receive (wirelessly) signals from the motor or hydraulic pressure drive (shown at 3 in FIG. 1), and may be used to control the speed of the motor/drive (shown at 3 in FIG. 1).

[0073] FIG. 6 is a block diagram of an example apparatus that may be utilized to facilitate a determination of gyroscopic rotation as described herein. The apparatus 140 may comprise hardware or a combination of hardware and software. In an example configuration, the functionality to facilitate a determination of gyroscopic rotation, as described herein, may reside in any one or combination of apparatuses. The apparatus 140 depicted in FIG. 6 may represent and perform functionality of any appropriate apparatus, or combination of apparatuses, such as, for example, embedded microprocessors 6 and 26 and memory 7, depicted in FIGS. 2A and 2B, or the like, or any appropriate combination thereof. It is emphasized that the block diagram depicted in FIG. 6 is exemplary and not intended to imply a specific implementation or configuration. Thus, the apparatus 140 may be implemented in a single device or multiple devices (*e.g.*, single processor or multiple processors, single server or multiple servers, single controller or multiple controllers, *etc.*). Multiple apparatuses may be distributed or centrally located. Multiple apparatuses may communicate wirelessly, via hard wire, or any appropriate combination thereof.

[0074] In an example configuration, the apparatus 140 may comprise a processor and memory coupled to the processor. The memory may comprise executable instructions that when executed by the processor cause the processor to effectuate operations associated determining gyroscopic rotation, as described herein. As evident from the herein description, the apparatus 140 is not to be construed as software *per se*.

[0075] In an example configuration, the apparatus 140 may comprise a processing portion 142, a memory portion 144, and an input/output portion 146. The processing portion 142, memory portion 144, and input/output portion 146 may be coupled together (coupling not shown in FIG. 6) to allow communications therebetween. Each portion of the apparatus 140 may comprise circuitry for performing functions associated with each respective portion. Thus, each portion may comprise hardware, or a combination of hardware and software. Accordingly, each portion of the apparatus 140 is not to be construed as software *per se*. The input/output portion 146 may be capable of receiving and/or providing information from/to a communications device and/or other apparatuses configured for determining gyroscopic rotation, as described herein. For example, the input/output portion 146 may include a wireless communications (*e.g.*, 2.5G/3G/4G/5G/GPS) card. The input/output portion 146 may be capable of receiving and/or sending video information, audio information, control information, image information, data, or any combination thereof. In an example configuration, the input/output portion 146 may be capable of receiving and/or sending information to determine a location of the apparatus 140 and/or the communications apparatus 140. In an example configuration, the input\output portion 146 may comprise a GPS receiver. In an example configuration, the apparatus 140 may determine its own geographical location and/or the geographical location of a communications device through any type of location determination system including, for example, the Global Positioning System (GPS), assisted GPS (A-GPS), time difference of arrival calculations, configured constant location (in the case of non-moving devices), any combination thereof, or any other appropriate means. In various configurations, the input/output portion 146 may receive and/or provide information via any appropriate means, such as, for example, optical means (*e.g.*, infrared), electromagnetic means (*e.g.*, RF, WI-FI, BLUETOOTH, ZIGBEE, etc.), acoustic means (*e.g.*, speaker, microphone, ultrasonic receiver, ultrasonic transmitter), or a combination thereof. In an example configuration, the input/output portion may comprise a WIFI finder, a two way GPS chipset or equivalent, or the like, or a combination thereof.

[0076] The processing portion 142 may be capable of performing functions associated with facilitating a determination of gyroscopic rotation, as described herein. For example, the processing portion 142 may be capable of, in conjunction with any other portion of the apparatus 140, installing an application for determining gyroscopic rotation, as described herein.

[0077] In a basic configuration, the apparatus 140 may include at least one memory portion 144. The memory portion 144 may comprise a storage medium having a concrete, tangible, physical structure. As is known, a signal does not have a concrete, tangible, physical structure. The memory portion 144, as well as any computer-readable storage medium described herein, is not to be construed as a signal. The memory portion 144, as well as any computer-readable storage medium described herein, is not to be construed as a transient signal. The memory portion 144, as well as any computer-readable storage medium described herein, is not to be construed as a propagating signal. The memory portion 144, as well as any computer-readable storage medium described herein, is to be construed as an article of manufacture having a concrete, tangible, physical structure.

[0078] The memory portion 144 may store any information utilized in conjunction with a determination of gyroscopic rotation, as described herein. Depending upon the exact configuration and type of processor, the memory portion 144 may be volatile 148 (such as some types of RAM), non-volatile 150 (such as ROM, flash memory, *etc.*), or a combination thereof. The apparatus 140 may include additional storage (*e.g.*, removable storage 152 and/or non-removable storage 154) including, for example, tape, flash memory, smart cards, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, universal serial bus (USB) compatible memory, or any other medium which can be used to store information and which can be accessed by the apparatus 140.

[0079] The apparatus 140 also may contain communications connection(s) 160 that allow the apparatus 140 to communicate with other devices, apparatuses, or the like. A communications connection(s) may comprise communication media. Communication media typically embody computer readable instructions, data structures, program modules or other data in a modulated data signal such as a carrier wave or other transport mechanism and includes any information delivery media. By way of example, and not limitation, communication media may include wired media such as a wired network or direct-wired connection, and wireless media such as acoustic, RF, infrared, and other wireless media. The term computer readable media as used herein includes both storage media and communication media. The apparatus 140 also may include input device(s) 156 such as keyboard, mouse, pen, voice input device, touch input device, *etc.* Output device(s) 158 such as a display, speakers, printer, *etc.* also may be included.

[0080] FIG. 7 illustrates a flow diagram of an example process 200 for facilitating a determination of gyroscopic rotation, as described herein. At step 202, a first rate of rotation may be determined via the periodicity sensor(s) 24. In an example configuration, the first rate of rotation may be accomplished when a vehicle comprising the mixing system 1 is stationary, when a vehicle comprising the mixing system 1 is moving slowly, when variations of signals provided by the periodicity sensor(s) 24 are less than a predetermined value(s), or the like, or any appropriate combination thereof. For example, if sensor values for the periodicity sensor(s) are consistent within a range (*e.g.*, plus/minus 5%), the initial rate of rotation may be determined. At step 204, the determined first rate of rotation may be used to calibrate a gyroscope parameter. Measurement of calibrated rotation may incorporate a scaling factor on the gyroscope rotation rate angle and a constant offset value. For example, an equation such as, $Y=mX + b$, may be utilized, wherein Y represents the calibrated measure of rotation (*e.g.*, rotation rate angle), m represents a scaling factor based on values obtained via the periodicity sensor(s), X represents a measure of rotation obtained from the gyroscope prior to calibration, and b represents any appropriate constant. Different calibration methods may be used depending on the type of periodicity sensor being used, the position of the gyroscope, the type of system being monitored, or other factors that may introduce uncertainty to calibration. After calibration, at step 206, the periodicity sensor(s) 24 may be monitored for a condition characteristic. In an configuration, the condition characteristic may be a function of the stability of the mixing system 1 being monitored. When the stability meets a predetermined condition, then at step 210, the gyroscope parameter(s) may be updated. If the predetermined condition is not met, then the periodicity sensor(s) 24 may continue to be monitored. For example, if the system 1 is moving around such that readings from the periodicity sensor(s) 24 fluctuate at a certain rate above the predetermined condition, then the system 1 may not be stable and the gyroscope parameter is not updated. The periodicity sensor 24 continues to be monitored. If the readings from the periodicity sensor 24 have a fluctuation rate below the predetermined condition, this may indicate the system 1 is stable, and the gyroscope parameter may be updated with information from the periodicity sensor 24.

[0081] An advantage of using a rotational monitoring system as described herein is that a more accurate determination can be made for a rate of rotation of a continuously rotating vessel. Additionally, the rotational speed may be monitored numerous times within a single rotation of the vessel. Determining accurate rotational speeds may be applicable for applications such as, but not limited to, determining slump in a concrete mixing vessel.

[0082] Another advantage includes reducing error in determining the rate of rotation by mitigating noise or other disturbances effecting the rotating vessel. For example, while a wireless accelerometer mounted on the rotating vessel may be sufficient for speed measurement when the vessel is rotating and stationary, or otherwise not moving in a vertical or horizontal direction, large errors can be introduced when the vessel is in motion. Inaccuracies can be introduced, for example, by external forces or motion of the vessel other than rotation. Further, using a gyroscope to measure rotational rate may be sufficient over a certain period of time; however, as is known in the art, gyroscopes tend to have a bias drift. The bias drift may impact rate of rotation information provided by the gyroscope. Therefore, the use of both a gyroscope and a periodicity sensor may overcome or prevent these issues and provide a more accurate rate of rotation by using information provided by each device.

[0083] While the disclosure is described herein using a limited number of configurations, these specific configurations are not intended to limit the scope of the disclosure as otherwise described and claimed herein. Modification and variations from the described configurations exist. More specifically, the following examples are given as a specific illustration of configurations of the claimed disclosure.

CLAIMS:

1. A system comprising:

a gyroscope coupled to a rotatable concrete mixer drum having spirally-mounted mixer blades and an axis of rotation, the gyroscope for providing a first signal corresponding to a rate of rotation of the mixer drum;

a periodicity sensor coupled to the rotatable concrete mixer drum, the periodicity sensor for providing a second signal corresponding to a period of rotation of the concrete mixer drum;

a processor; and

memory coupled to the processor, the memory comprising executable instructions that when executed by the processor cause the processor to effectuate operation of the concrete mixer drum having the spirally-mounted mixer blades, whereby rotation of the mixer drum in a first direction causes contents of the drum to be mixed, and whereby rotation of the mixer drum in a second direction opposite the first direction causes the contents of the drum to be expelled from the drum, the instructions executable by the processor comprising:

receiving the first signal;

receiving the second signal;

determining calibration information based on the received first signal and the received second signal; and

generating an output signal corresponding to a calibrated rate of a rotation of the concrete mixer drum based on the calibration information.

2. The system of claim 1, wherein the gyroscope comprises a Micro-Electro Mechanical System (MEMS).

3. The system of claim 1 or 2, wherein the rate of rotation is an angular velocity of the rotatable concrete mixer drum.

4. The system of any one of claims 1 to 3, wherein the gyroscope, the periodicity sensor, and the processor are located within a common housing enclosure mounted onto the rotatable concrete mixer drum.

5. The system of claim 4, wherein the gyroscope is mounted on the concrete mixer drum at a distance from the rotational axis of the concrete mixer drum.

6. The system of claim 5, wherein the accelerometer is mounted on the concrete mixer drum at a distance from the rotational axis of the concrete mixer drum.

7. The system of any one of claims 1 to 6, wherein the periodicity sensor comprises an accelerometer.

8. The system of any one of claims 1 to 7, wherein the at least one periodicity sensor comprises a hydraulic pressure sensor.

9. The system of any one of claims 1 to 8, wherein the instructions executable by the processor further comprise:

> transmitting an indication of the calibrated rate of rotation of the concrete mixer drum.

10. The system of any one of claims 1 to 9, wherein the instructions executable by the processor further comprise:

> determining whether the second signal is stable, wherein when the second signal is stable the gyroscope is calibrated.

11. The system of any one of claims 1 to 10, further comprising a concrete slump monitoring system, the slump monitoring system comprising:

> a second processor, the second processor configured to receive the output signal corresponding to the calibrated rotational rate provided by the processor; and
>
> an energy sensor operably connected to the second processor, the energy sensor for measuring the energy required to rotate the rotatable mixer drum.

12. The system of any one of claims 1 to 11, wherein the rotatable concrete mixer drum is mounted onto a truck.

13. The system of any one of claims 1 to 12, wherein the gyroscope is configured to provide the first signal to the processor numerous times within a single rotation of the concrete mixer drum.

14. The system of any one of claims 1 to 13, wherein the instructions executable by the processor further comprise:

determining a calibration constant, to determine stability of either the gyroscope or periodicity sensor, while the drum is rotating at different speeds.

15. The system of any one of claims 1 to 14, wherein the axis of rotation is between 10 and 20 degrees with respect to ground.

16. A system comprising:

a gyroscope coupled to a rotatable mixer drum having spirally-mounted mixer blades and an axis of rotation, the gyroscope for providing a first signal corresponding to a rate of rotation of the mixer drum, the mixer drum being effective for mixing a displaceable material chosen from powders, particles, grains and seeds, cereals, coffee, detergents, pharmaceutical materials, and concrete;

a periodicity sensor coupled to the rotatable mixer drum, the periodicity sensor for providing a second signal corresponding to a period of rotation of the mixer drum;

a processor; and

memory coupled to the processor, the memory comprising executable instructions that when executed by the processor cause the processor to effectuate operation of the mixer drum having the spirally-mounted mixer blades, whereby rotation of the mixer drum in a first direction causes contents of the drum to be mixed, and whereby rotation of the mixer drum in a second direction opposite the first direction causes the contents of the drum to be expelled from the drum, the instructions executable by the processor comprising:

receiving the first signal;

receiving the second signal;

determining calibration information based on the received first signal and the received second signal; and

generating an output signal corresponding to a calibrated rate of a rotation of the mixer drum based on the calibration information.

17. The system of claim 16, wherein the particles are dry or in slurry, paste, or suspension.

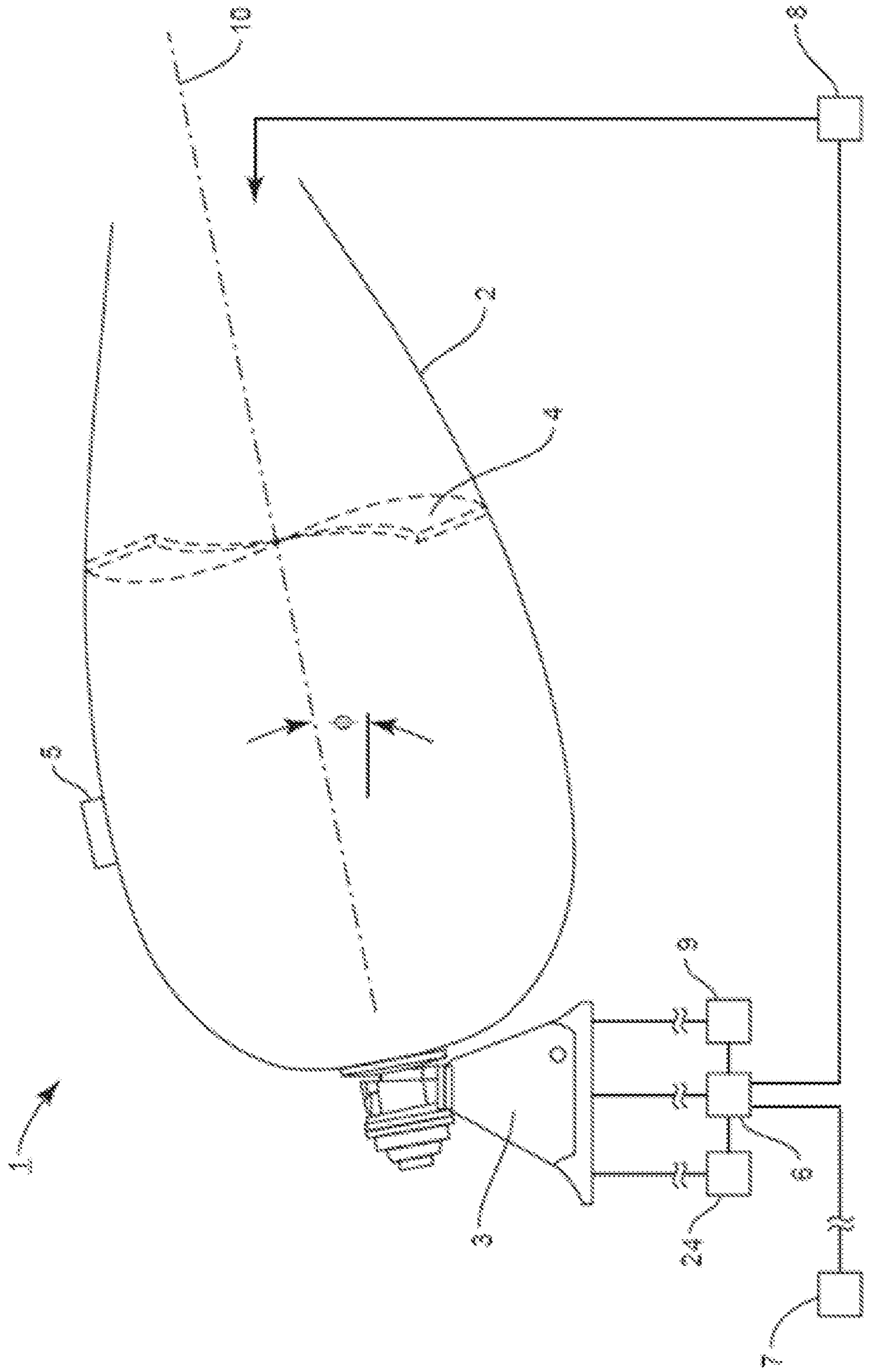
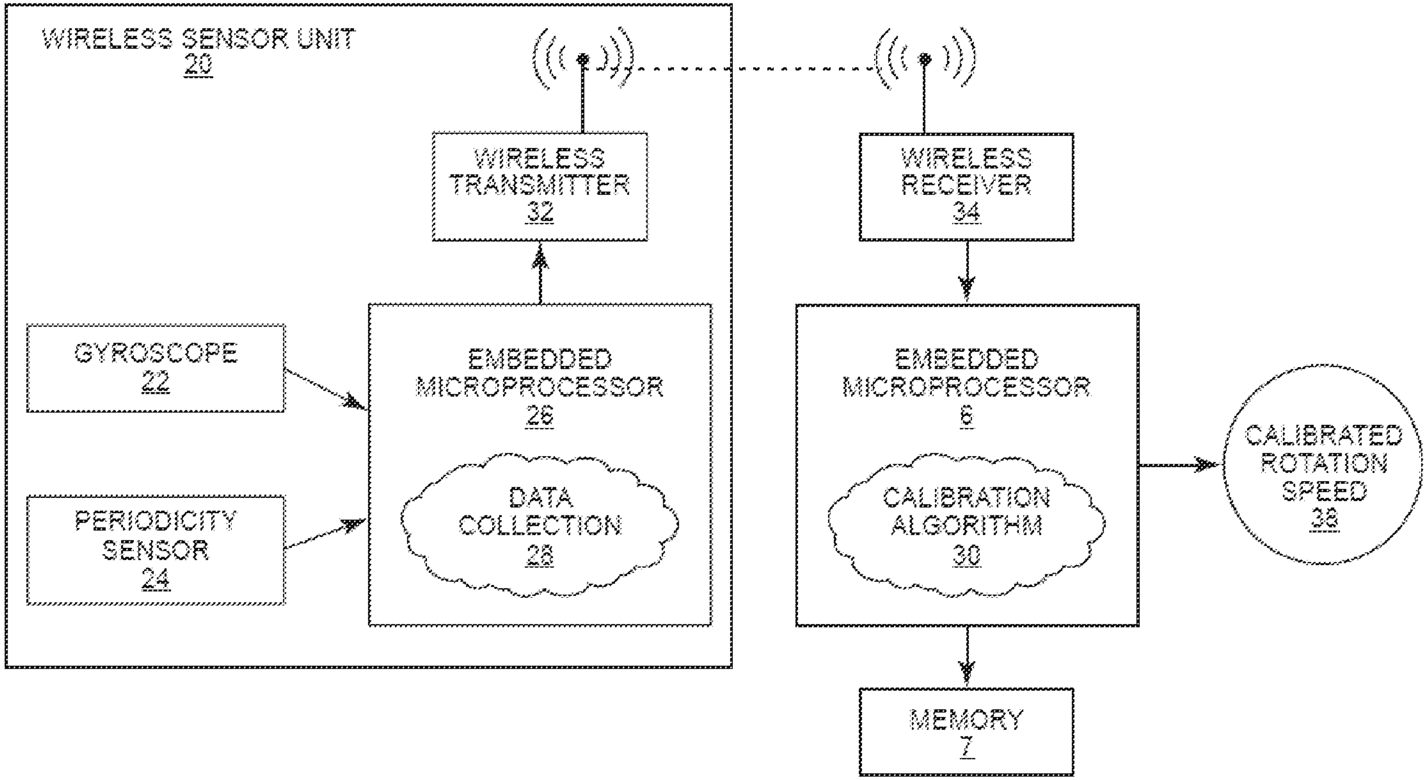


FIG. 1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20
WIRELESS TRANSMITTER
32
GYROSCOPE
22
PERIODICITY SENSOR
24
EMBEDDED MICROPROCESSOR
26
DATA COLLECTION
28
WIRELESS RECEIVER
34
EMBEDDED MICROPROCESSOR
6
CALIBRATION ALGORITHM
30
CALIBRATED ROTATION SPEED
38
MEMORY
7

FIG. 2A

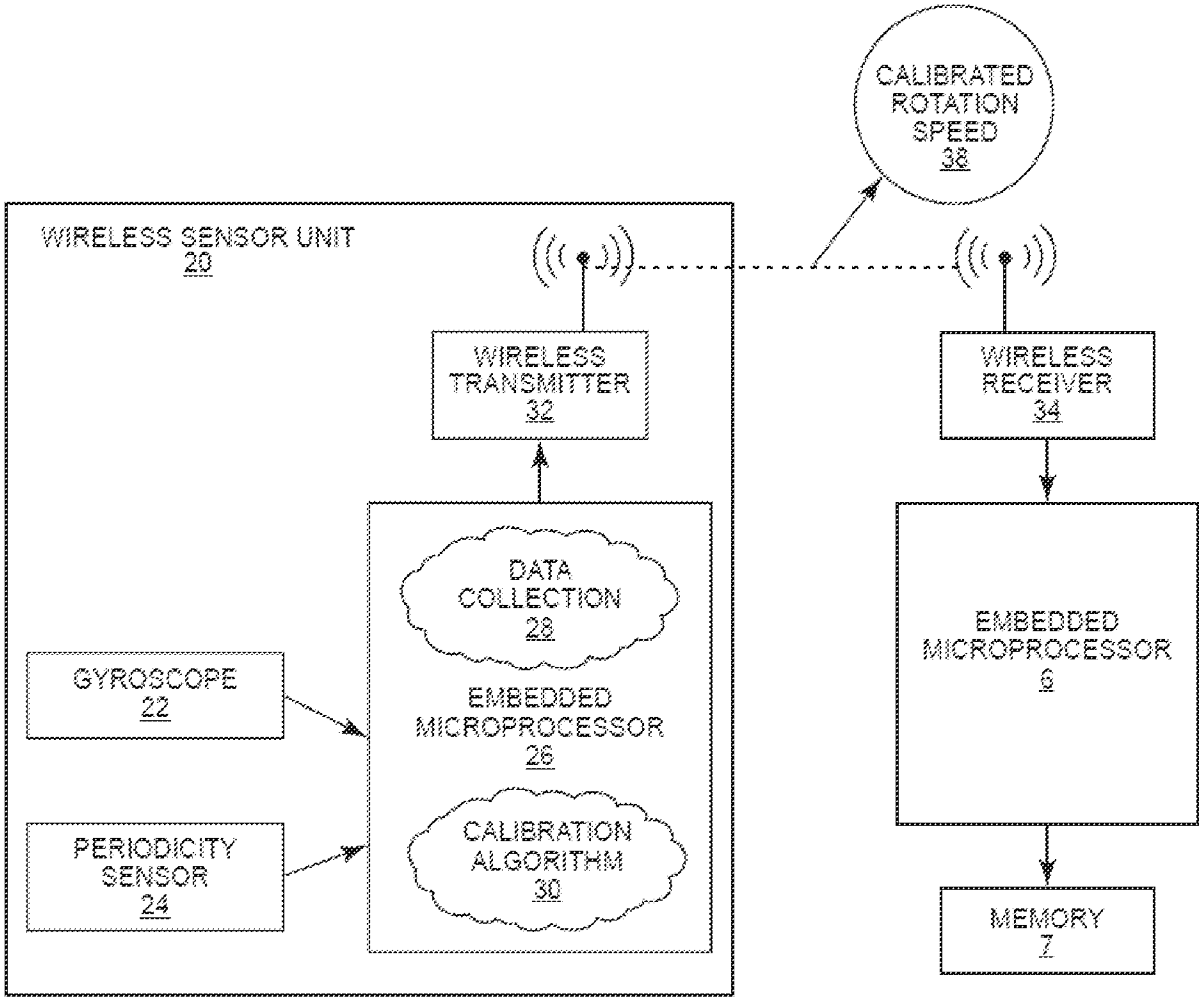

CALIBRATED ROTATION SPEED 38
WIRELESS SENSOR UNIT 20
WIRELESS TRANSMITTER 32
WIRELESS RECEIVER 34
DATA COLLECTION 28
EMBEDDED MICROPROCESSOR 26
CALIBRATION ALGORITHM 30
GYROSCOPE 22
PERIODICITY SENSOR 24
EMBEDDED MICROPROCESSOR 6
MEMORY 7

FIG. 2B

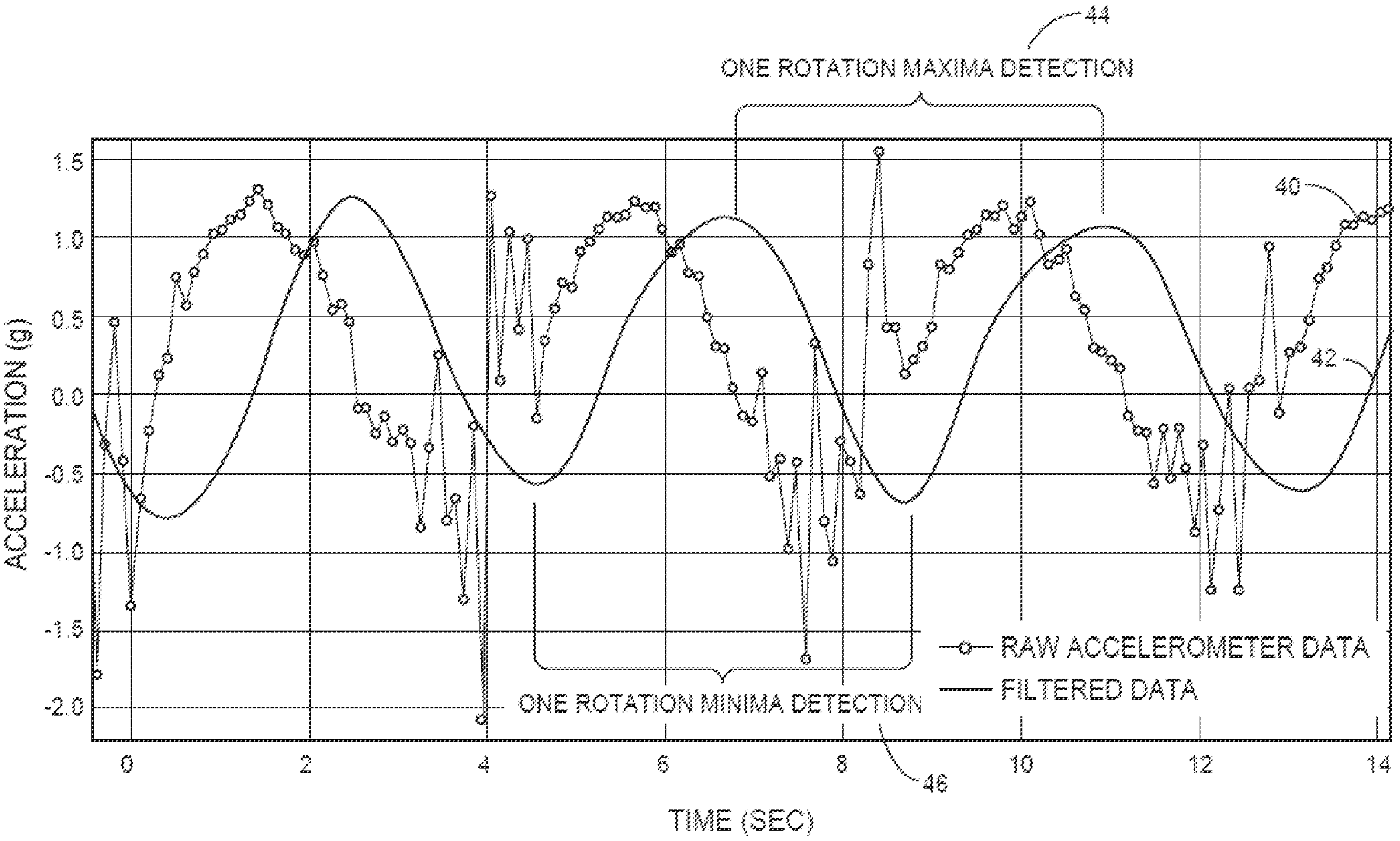

44
ONE ROTATION MAXIMA DETECTION
ACCELERATION (g)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
40
42
RAW ACCELEROMETER DATA
FILTERED DATA
ONE ROTATION MINIMA DETECTION
46
0
2
4
6
8
10
12
14
TIME (SEC)

FIG. 3A

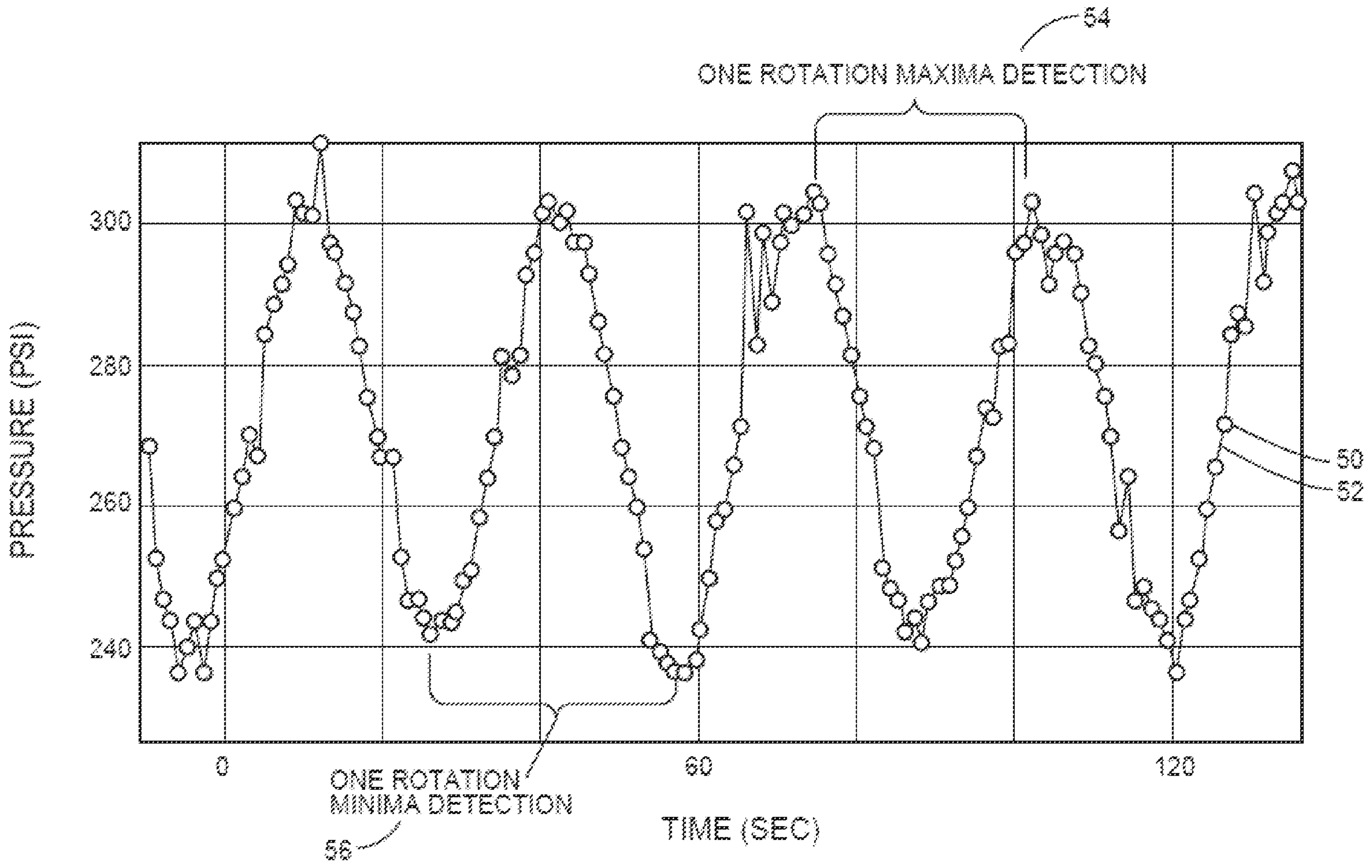

54
ONE ROTATION MAXIMA DETECTION
PRESSURE (PSI)
300
280
260
240
0
60
120
TIME (SEC)
50
52
ONE ROTATION
MINIMA DETECTION
56

FIG. 3B

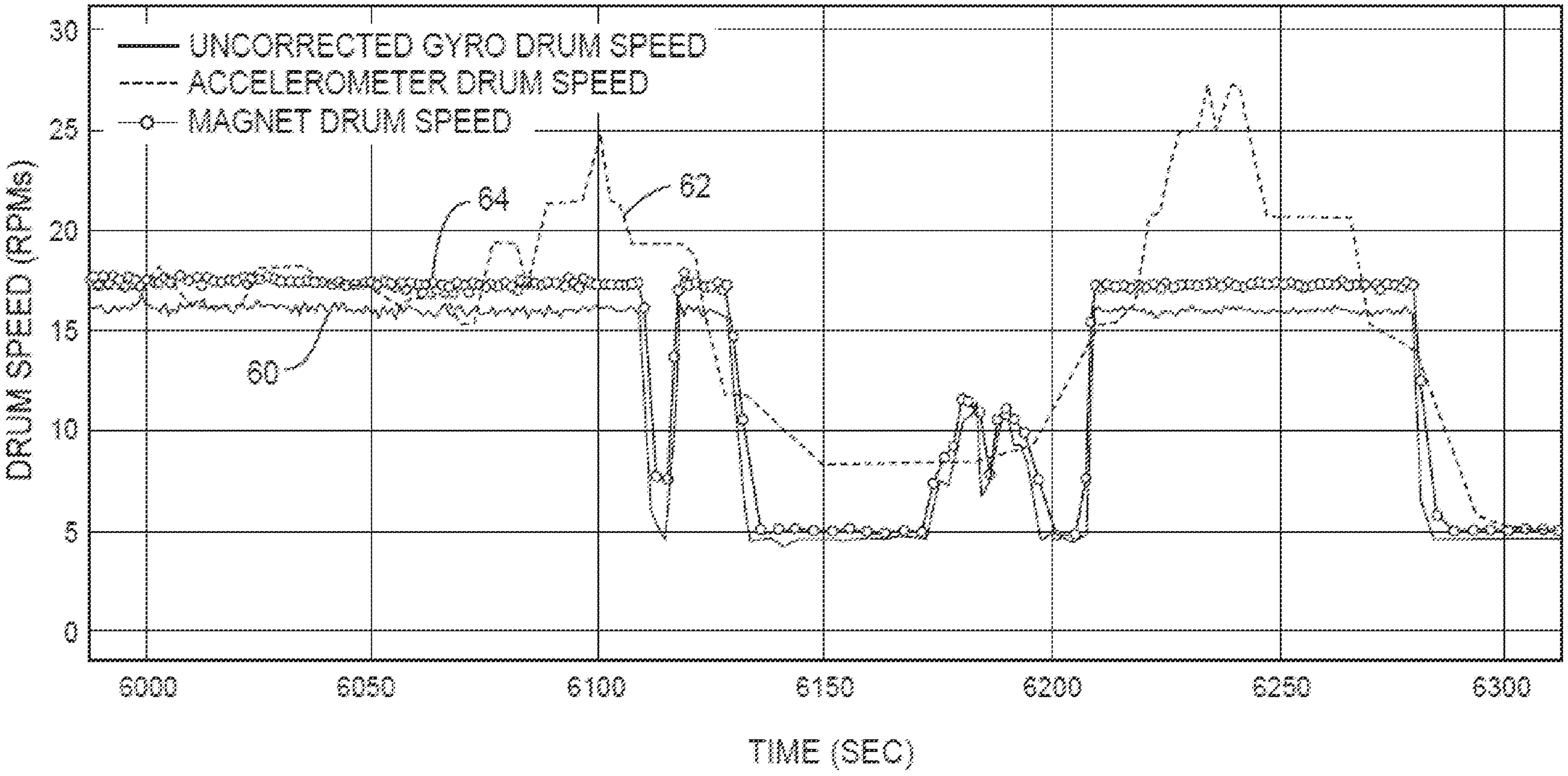

UNCORRECTED GYRO DRUM SPEED
ACCELEROMETER DRUM SPEED
MAGNET DRUM SPEED
DRUM SPEED (RPMs)
TIME (SEC)
0
5
10
15
20
25
30
6000
6050
6100
6150
6200
6250
6300
60
62
64

FIG. 4A

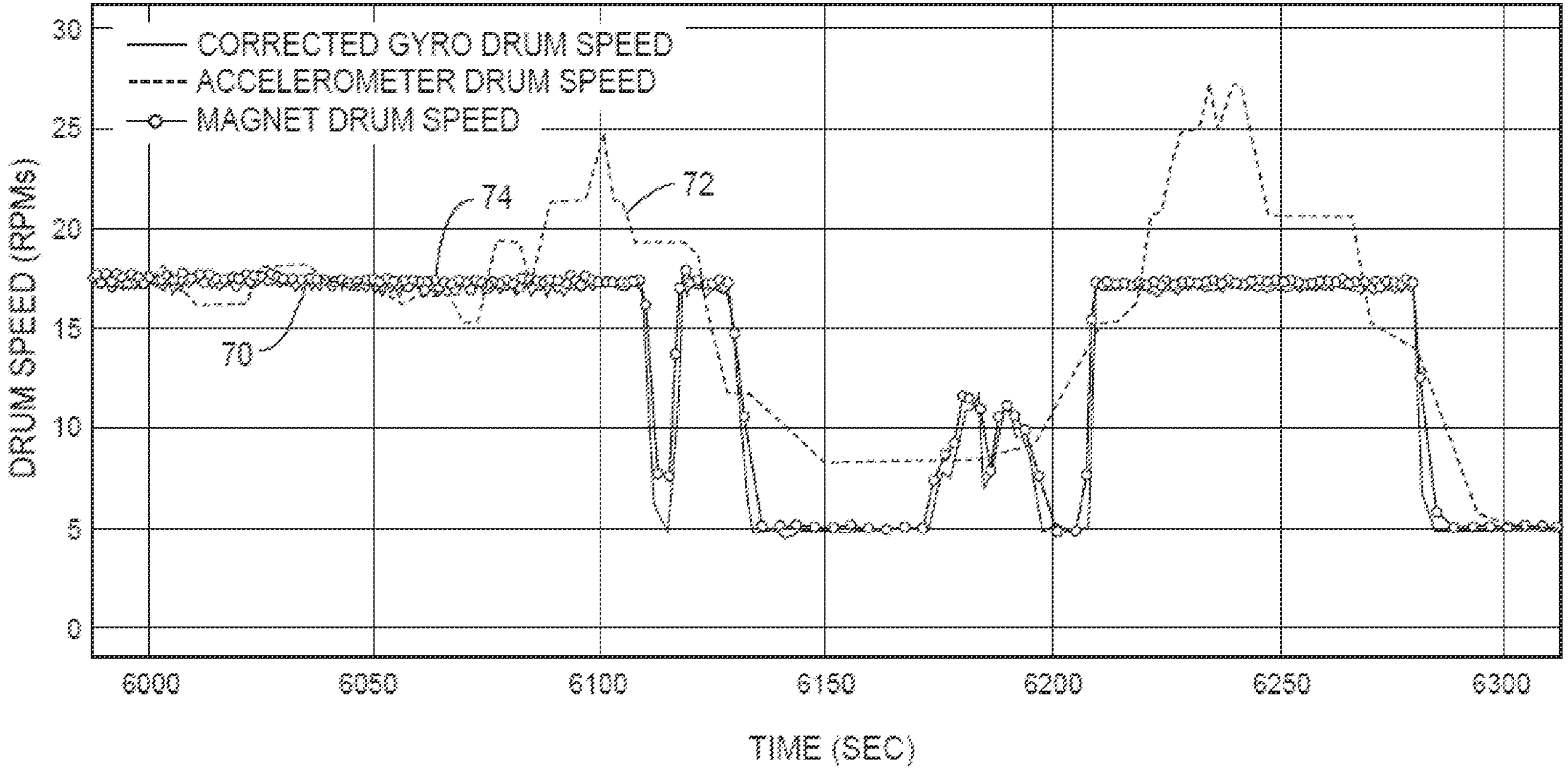

CORRECTED GYRO DRUM SPEED
ACCELEROMETER DRUM SPEED
MAGNET DRUM SPEED
74
72
70
DRUM SPEED (RPMs)
30
25
20
15
10
5
0
6000
6050
6100
6150
6200
6250
6300
TIME (SEC)

FIG. 4B

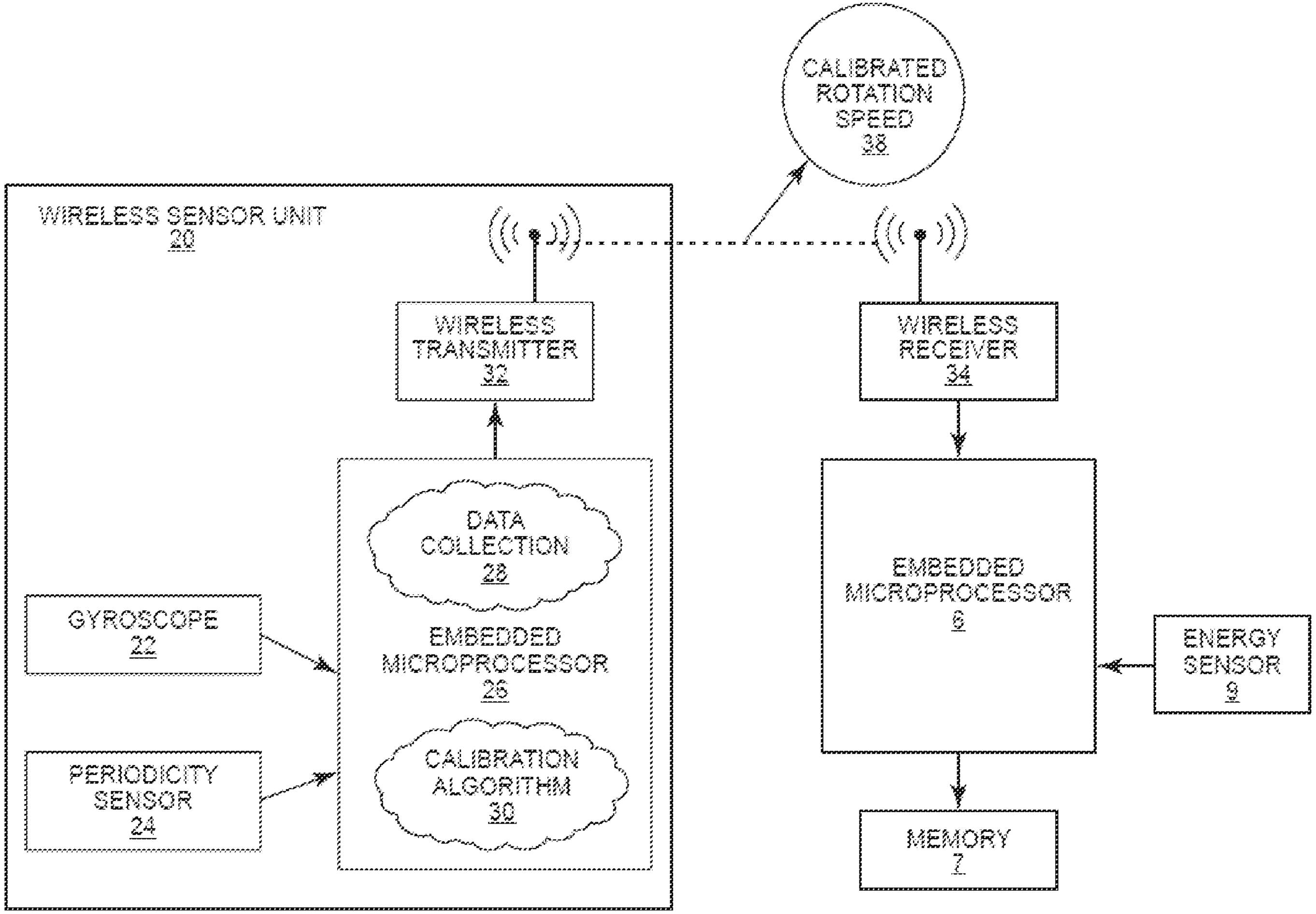

WIRELESS SENSOR UNIT
20
WIRELESS TRANSMITTER
32
GYROSCOPE
22
PERIODICITY SENSOR
24
DATA COLLECTION
28
EMBEDDED MICROPROCESSOR
26
CALIBRATION ALGORITHM
30
CALIBRATED ROTATION SPEED
38
WIRELESS RECEIVER
34
EMBEDDED MICROPROCESSOR
6
ENERGY SENSOR
9
MEMORY
7

FIG. 5

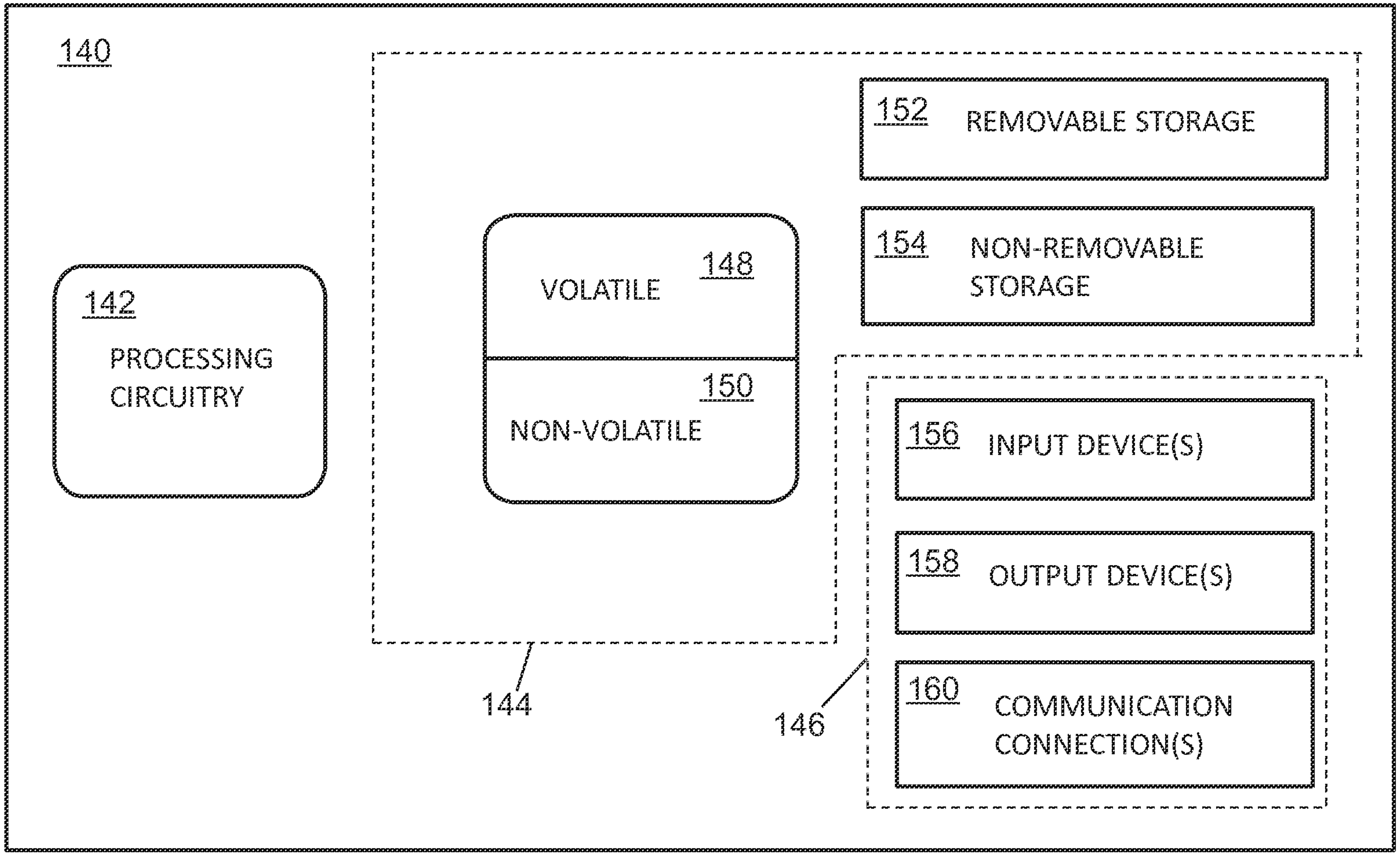

140
142
PROCESSING CIRCUITRY
VOLATILE
148
150
NON-VOLATILE
152
REMOVABLE STORAGE
154
NON-REMOVABLE STORAGE
156
INPUT DEVICE(S)
158
OUTPUT DEVICE(S)
160
COMMUNICATION CONNECTION(S)
144
146

FIG. 6

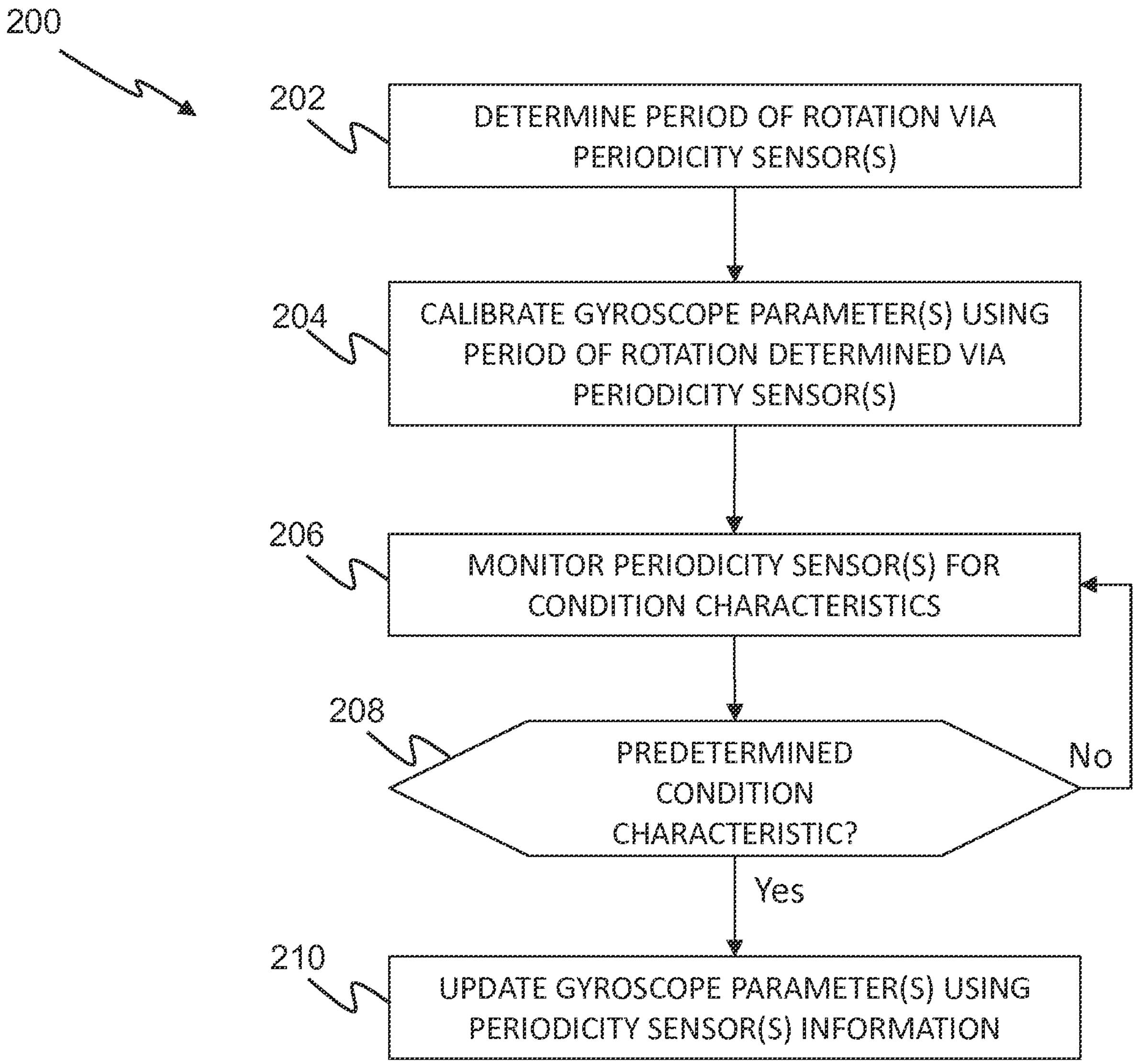
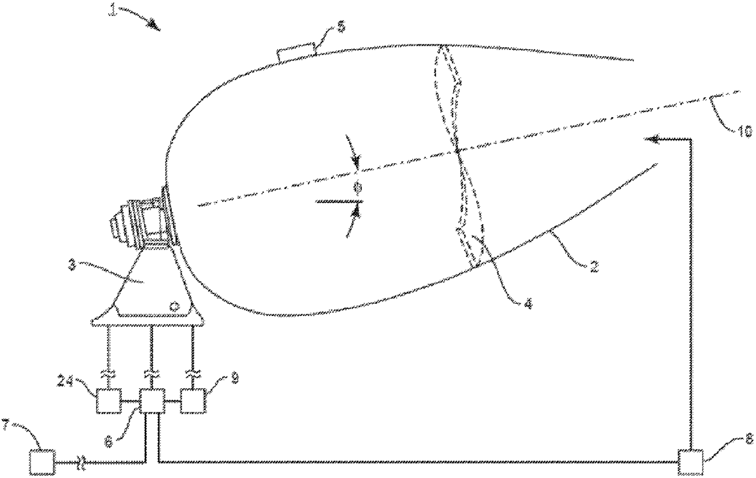

200
202
DETERMINE PERIOD OF ROTATION VIA PERIODICITY SENSOR(S)
204
CALIBRATE GYROSCOPE PARAMETER(S) USING PERIOD OF ROTATION DETERMINED VIA PERIODICITY SENSOR(S)
206
MONITOR PERIODICITY SENSOR(S) FOR CONDITION CHARACTERISTICS
208
PREDETERMINED CONDITION CHARACTERISTIC?
No
Yes
210
UPDATE GYROSCOPE PARAMETER(S) USING PERIODICITY SENSOR(S) INFORMATION

FIG. 7


1
5
10
θ
3
2
4
24
9
6
7
8

Schedule “B”

Canadian Patent No. 3,007,480

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CA 3007480 C 2023/03/28

(11)(21) **3 007 480**

(12) **BREVET CANADIEN**
CANADIAN PATENT

(13) **C**

(86) **Date de dépôt PCT/PCT Filing Date:** 2015/12/07
(87) **Date publication PCT/PCT Publication Date:** 2017/06/15
(45) **Date de délivrance/Issue Date:** 2023/03/28
(85) **Entrée phase nationale/National Entry:** 2018/06/05
(86) **N° demande PCT/PCT Application No.:** US 2015/064257
(87) **N° publication PCT/PCT Publication No.:** 2017/099711

(51) **Cl.Int./Int.Cl.** ***B28C 7/02*** (2006.01)

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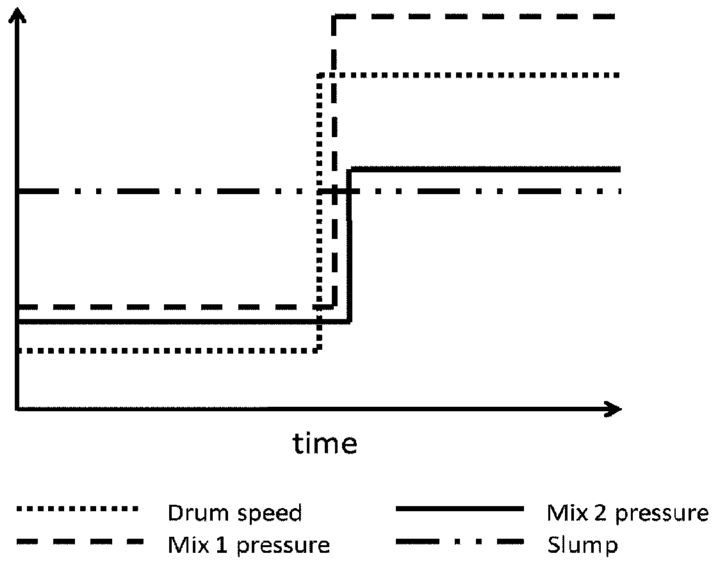
(74) **Agent:** SMART & BIGGAR LP

(54) **Titre : ETALONNAGE DE CONTROLE DE BETON A LARGE PLAGE DE VITESSE**
(54) **Title: WIDE SPEED RANGE CONCRETE MONITORING CALIBRATION**



(57) **Abrégé/Abstract:**
A method and system for concrete monitoring calibration using truck-mounted mixer drum jump speed data selectively assimilated from previous deliveries. The method involves measuring energy at a first drum speed and a second drum speed. Slump is calculated using low speed energy/speed/slump curve data, or pre-stored equation wherein slump is derived as a function of slope of the line. The energy, speed, slump relationship in the provided concrete is compared to at least two pre-stored data curves across drum speed ranges of 15 0.5 RPM - 6 RPM and 6 RPM - 20 RPM, to ascertain whether the provided concrete matches any of the stored curve data; either activating the monitoring system for all drum speed ranges where a match is confirmed or allowing the monitoring system to calculate slump only at low drum speeds.

Canada *http://opic.gc.ca* · Ottawa-Hull K1A 0C9 · *http://cipo.gc.ca* OPIC CIPO
OPIC · CIPO 191

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 June 2017 (15.06.2017)

WIPO | PCT

(10) International Publication Number
WO 2017/099711 A1

(51) International Patent Classification: ***B28C 7/02*** (2006.01)

(21) International Application Number: PCT/US2015/064257

(22) International Filing Date: 7 December 2015 (07.12.2015)

(25) Filing Language: English

(26) Publication Language: English

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) Title: WIDE SPEED RANGE CONCRETE MONITORING CALIBRATION

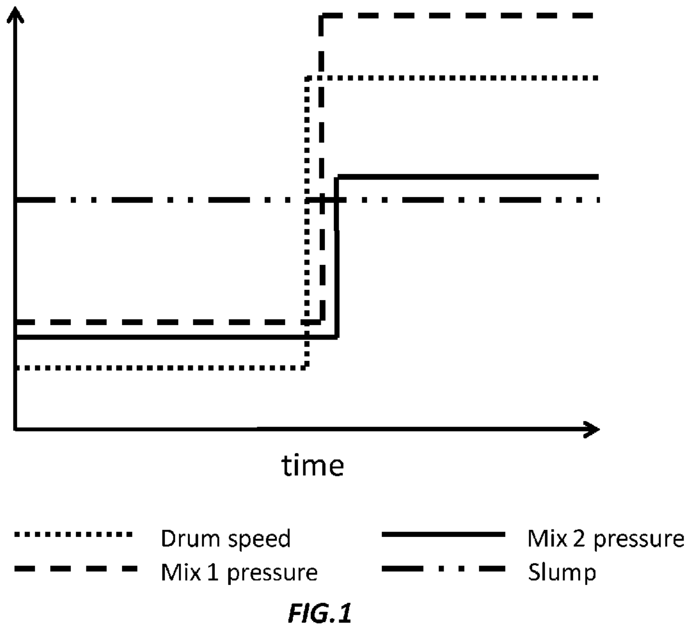


FIG.1

(57) Abstract: A method and system for concrete monitoring calibration using truck-mounted mixer drum jump speed data selectively assimilated from previous deliveries. The method involves measuring energy at a first drum speed and a second drum speed. Slump is calculated using low speed energy/speed/slump curve data, or pre-stored equation wherein slump is derived as a function of slope of the line. The energy, speed, slump relationship in the provided concrete is compared to at least two pre-stored data curves across drum speed ranges of 15 0.5 RPM - 6 RPM and 6 RPM - 20 RPM, to ascertain whether the provided concrete matches any of the stored curve data; either activating the monitoring system for all drum speed ranges where a match is confirmed or allowing the monitoring system to calculate slump only at low drum speeds.

WO 2017/099711 A1

WIDE SPEED RANGE CONCRETE MONITORING CALIBRATION

Field of the Invention

The present invention relates to measurement of concrete, and, more particularly, to a method and system for wide speed range concrete monitoring calibration using truck-mounted drum jump speed data selectively assimilated from different previous concrete deliveries.

Background of the Invention

In US Patents No. 8,020,431, No. 8,746,954, and No. 8,989,905 (assigned to Verifi LLC), Cooley et al. explained that when a concrete mix was rotated within a truck-mounted mixer drum at a stable (constant) speed, the slump of the concrete could be calculated by reference to an empirically generated "lookup table" that identified the slump value associated with the average hydraulic pressure required to rotate the concrete drum at the reference drum speed, e.g., 3 RPM. Hence, a slump value could be calculated, with respect to the reference drum speed, for each pressure value within a wide range of pressure readings in the lookup table. *See* US 8,020,431, col. 11, lines 7-13.

However, while the relationship between pressure and drum speed is observed by Cooley et al. to be "approximately" linear when drum speed is about 3 RPM, it becomes pronouncedly "non-linear" at higher drum speeds, e.g., 10 RPM, which is higher than the reference speed of the lookup table. *See* US 8,020,431, *col. 11, ll. 14-17, 55-58.*

While this does not present a serious issue for low speed mixing (e.g., 3 RPM) as typically occurs during transit from the batching plant, Cooley et al. noted that there were situations in which faster mixing speeds were used. They discuss at length, for example, the batch mixing which occurs immediately after loading of the mix components into the truck drum: when the truck moves to a "slump rack" where it performs higher speed mixing, then adjusts the load, then performs more high speed mixing, and then slows down the drum to travel speed and departs for the delivery site from the plant. *See* US 8,020,431, *col. 11, ll. 20-26.*

Cooley et al. postulated that a compensation factor, called a *calibrated rpm factor* or "RPMF," could be assigned to each truck to support management of higher mixing rates and thereby avoid "manual" or empirical calibration of the truck at higher drum speeds. *See* US 8,020,431, col. 11, ll. 14-17, 35-40. Their belief was that RPMF was different from truck to truck and based upon "a variety of reasons [which included] the buildup in the drum of the truck, fin shape, hydraulic efficiency variation, and others." *See* US 8,020,431, col. 12, ll. 23-26.

As Cooley et al. desired to avoid the burdensome task of calibrating and re-calibrating the RPMF for each truck, they postulated a self-calibration process using a "theory of slump continuity" which was based on the premise that slump of the concrete mix remains the same during a sudden change in the drum speed:

> *". . . The theory of slump continuity is that, over a short period of time, absent extraneous factors such as addition of water or mixture, slump remains relatively constant even if drum speed changes. Therefore the rpm compensation described above may be tested whenever there is a drum speed change, by comparing an observed change in average pressure caused by the drum speed change, to the predicted change in average pressure. If the predicted pressure change is erroneous, the rpm factor RMPF may be adjusted."*

See US 8,020,431, col. 11, lines 30-39.

The self calibration process based on the above slump continuity theory, as typified by drum speed changes that occur at batch plant mixing, was further described by Cooley et al. as follows:

> *"The self calibration proceeds as follows: when a drum speed change from a higher to a lower speed occurs, the average pressure at the higher speed (before the speed change) is used to compute a predicted pressure at 3 rpm, and the average pressure at the lower*

> *speed (after the speed change) is similarly used to compute a predicted pressure at 3 rpm, in each case using the process described above. If the predicted 3 rpm pressure derived from the higher speed is larger than the predicted 3 rpm pressure derived from the lower speed, this indicates that the RPMF overestimating the pressure increase [is] caused by speed reduction, and the RPMF is reduced so that the two predicted 3 rpm pressures are equal. If the predicted 3 rpm pressure derived from the lower speed is larger than the predicted 3 rpm pressure derived from the higher speed, this indicates that the RPMF is underestimating the pressure increase caused by speed reduction, and the RPMF is increased so that two predicted 3 rpm pressures are equal.*

See US 8,020,431, col. 12, lines 50-67.

The present inventors propose to follow the "theory of slump continuity" described by Cooley et al., but, on the other hand, they chart out a fundamentally different approach in resolving the inaccuracy of rheology monitoring which arises from the *non-linear* relationship between force or pressure and high drum speeds. *"At higher drum speeds, the RPMF increases," observed Cooley et al., who believed that for "the purposes of slump calculation, the increase in the RPMF is handled in a piecewise linear fashion."*

The present inventors believe that the arithmetic adjustment suggested by Cooley et al. *("at drum speeds from 6-10 rpm, the RPMF is doubled and above 10 RPM, the RPMF is quadrupled")* does not resolve the "non-linearity" problem at higher mixing speeds because it only involved one mix design. The present inventors discovered that concrete mix design differences introduce greater variability and non-linearity within energy/slump/drum-speed curve data; this lack of curvilinear predictability is more pronounced at higher drum mixing speeds (~10 RPM), and most pronounced at the highest mixing speeds (16-20 RPM or more).

Until the present invention, it has remained the case that automated slump monitoring systems do not self-calibrate above the low speed mixing range (above 3-4 RPM) and that slump curves still need to be manually generated using standard slump cone measurements. In the higher ranges of drum rotation speeds, the viscosity of concrete mixes can be profoundly affected by mix constituents and proportions, and, in turn, these factors can cause variable effects on the pressure or force associated with moving the concrete at the higher drum rotation speeds (*See e.g.*, Application of Rheological Measurements to Practical Control of Concrete in Rheology of Fresh Cement and Concrete, ed. P.F.G. Banfill, British Society of Rheology, Tattersall, 1991; *See also* Testing and Modeling of Fresh Concrete Rheology, Ferraris, de Larrard; NIST (Report NISTIR 6094) 1998.

Consequently, without taking the time and expending the labor to calibrate the slump monitoring system across the entire range of drum speeds, e.g., from 0.5 to 20 RPM, in ladder-like fashion, commercial monitoring systems are only used in low speed mixing applications where the speed range is typically 2-4 or 2-5 RPM at best.

The ability to measure slump only at low speeds is disadvantageous for many reasons. First, measuring at low speed is time-consuming, because often one or more revolutions of the drum are required before concrete mixes stabilize. This operation takes several minutes. As the ready-mix industry is essentially a shipping industry, wasted time is costly. Time can also be wasted during fluid additions used for adjusting slump.

Second, while the concrete can only be accurately monitored when the drum speed is below a certain RPM level, various concrete mix plants sometimes impose different mixing speed regimes for their particular mix designs, and these do not always coincide with optimum drum speeds required by the slump monitoring system.

Third, current typical industry practices prolong the delivery process whereby the slump monitoring system is only calibrated accurately for low speeds (e.g., 0.5-5 RPM). However, the present inventors are mindful of the industry practices described by ASTM C94, which requires that, if fluid additions are made to the concrete before pouring at the construction site, the speed of the mixing drum must be raised to high speed to ensure homogeneity (completeness of mixing) of the delivered concrete. If 30 rotations are required at high speed, during which an automated slump monitoring system cannot provide an accurate reading because it is not calibrated for that particular mix design at high speed, then the drum speed must be lowered after 30 rotations to a lower speed for monitoring purposes; and, if the monitored slump does not match a target slump (i.e., the slump value specified for the pouring event) and a fluid must be added to adjust the concrete mix to the desired slump, the drum speed must be increased again to high RPM until a homogenous mixture is attained before the mixer drum can again be slowed down so that it returns to the lower speed at which the system was calibrated, whereby accurate slump monitoring can be better achieved. All this, according to ASTM C94, must be done within 15 minutes from the first addition; and, hence, repeated additions may not necessarily be done within this time frame.

Hence, slump monitoring systems that are calibrated only for low speed measurement require that mixer drum speed be dropped to below 5 RPM, and, more typically, to 2-3 RPM, after which more adjustments at higher drum speeds are often necessary.

The present inventors believe that there has been a long felt need for an automated calibration process that will permit accurate adjustments to be made to the rheology (e.g., slump, slump flow, yield stress, etc.) of the current concrete load using such monitoring systems, a process that will ensure accurate and efficient monitoring that will allow for high speed mixing monitoring. This would be beneficial for industrial use of concrete delivery truck-mounted mixer drums.

Summary of the Invention

In surmounting the disadvantages of prior art approaches, the present invention provides a method and system for wide speed range concrete monitoring calibration using truck-mounted mixer drum "jump speed" curve data that is selectively assimilated from different previous concrete deliveries. Surprisingly, the present invention permits the use of jump speed data obtained from prior concrete deliveries involving different concrete mix designs.

The terms "curve data" or "data curves" are used herein to refer to data comprising energy associated with rotating a concrete mix, in terms of hydraulic pressure required for rotating the concrete or force exerted by concrete moving against a probe (e.g., strain gauge) mounted within the rotating drum (both type of energy values hereinafter designated "E") at given constant mixer drum speed values (speed being hereinafter designated "V") which can be plotted graphically as a relationship from which concrete slump ("S") or other rheology value can be calculated. Slump ("S") will be understood to be used interchangeably with other rheology concepts such as slump flow, yield stress, workability, and the like which are capable of being monitored using processor-controlled systems on concrete mixer trucks. Accordingly, the concepts "jump speed data" and "jump speed curve data" can be used herein to refer to the "E/V/S" relationship useful for characterizing the rheology of concrete mixes.

While the use of jumps in mixer drum speed (sudden changes) have been used in the past to measure rheological properties of concrete (e.g., US Patent 8,764,272 of Hazrati et al., owned by Verifi LLC of Cambridge, MA), including the slump of concrete (*e.g.*, WO 2013/144528 A1 of Lafarge), also as mentioned in Cooley et al. as just discussed in the background section, the prior use of jump speed data has been limited in commercial applicability. This is because real-time measurement involving two or more different drum speeds requires large amounts of time. A change in speed from below 6 RPM (e.g., 1-3 RPM) to 8, 10, 15, 18, and 20 RPM or more, and then back to below 6 RPM does not happen frequently during delivery operations.

While it is discussed in ASTM C94 (and Cooley et al.) that high "mixing" speed is used after batching components together, the mixer drum is slowed to "agitation" speed (e.g., 2-3 RPM) for transit purposes. This reduces the risk of having concrete spill out of the truck or causing it to tip over. Thus, high speed jumps do not normally occur during transit, and hence it is believed that the present invention provides a surprisingly novel and inventive approach.

The present inventors realized that they could obtain jump speed data curves from previous concrete deliveries and that these contain data associated with the energy values (pressure or force) associated with rotating concrete (including higher and very high drum speed ranges), the drum speed, and calculated slump (e.g., as might be calculated using data curves at low speed or using pre-established mathematical relationships), could be used preferentially for determining whether it is possible for the monitoring system to calibrate the processor-controlled concrete monitoring system such that slump or other rheology of the current concrete can be monitored at the higher and highest mixing speeds (e.g., 6-20 RPM range).

Accordingly, some embodiments of the present invention advantageously incorporate what hitherto is considered an inconvenient, nuisance practice under ASTM C94. This practice involves truck operators rotating the drum at a minimum of 30 revolutions if fluid was dosed at any time before the concrete is poured. The present inventors realized that the concrete is most likely, in these pre-pour drum jump speed events, to be in a state of "equilibrium" and that it was important for the concrete to be in an equilibrium state for the theory of slump continuity to be applied. A state of equilibrium can be confirmed, for example, by measuring the energy (e.g., pressure or force) associated with rotating the mixer drum at constant speed, and confirming that the average energy value over two or more successive drum rotations does not vary (e.g., by plus or minus 5% or 10%) from one rotation to the next. Alternatively, equilibrium can be confirmed by measuring the energy (e.g. pressure or force) associated with rotating the mixer drum at constant speed, and confirming that the instantaneous energy value at an initial point in time does not vary (e.g. by plus or minus 5% or 10%) from the instantaneous energy value at a point one revolution from the initial point.

Hence, an exemplary method of the present invention for concrete monitoring calibration using a processor-controlled system and a delivery mixer truck mixer drum (which rotates at a non-vertical angle with respect to the ground), comprises:

(A) monitoring concrete provided in the mixer drum by measuring, while the concrete is in a state of equilibrium, the energy ("E1") associated with rotating the concrete at a first constant speed ("V1") and energy ("E2") associated with rotating the concrete at a second constant speed ("V2") after a speed jump of plus or minus at least 2.5 rotations per minute (RPM);

(B) calculating a slump value ("S") for the provided concrete based on E1, V1, E2, and V2;

(C) comparing E1, V1, E2, V2, and S as calculated from step (B) with at least two data curves stored in processor-accessible memory, the stored data curves defining an E/V/S relationship for purposes of calculating slump across drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM, the at least two stored data curves comprising data obtained from previous deliveries of concrete when the previous concrete was in a state of equilibrium and comprising energy (E) values measured before and after at least 2.5 RPM jumps in constant drum speed (V) and slump values (S) as calculated from the previously stored E and V data, whereby the process-controlled system determines whether any of the at least two stored data curves match the E1, V1, E2, V2, and S values of the provided concrete; and

(D) monitoring the slump of the provided concrete in the mixer drum by calculating slump through measurement of the energy associated with rotating the concrete

  (i) within 0.5 RPM - 6 RPM and within 6 RPM - 20 RPM drum speed ranges, based on one of the at least two stored data curves which is determined to constitute a match in step (C), and providing a visual indication that slump is being calculated by the system for drum speeds higher than 6 RPM; or

  (ii) within the 0.5 RPM - 6 RPM range only, if none of the stored curve data is determined to constitute a match in Step (C), and initiating an alert to a system operator or the truck driver, or dispatch center, that the system is active only for monitoring at drum speeds below 6 RPM.

In another embodiment of the present invention, the stored at least two data curves in step (C) are obtained from different previous concrete deliveries.

In some embodiments, the stored at least two data curves in step (C) comprise mixer drum data of jumps in rotation speed occurring after arrival of the delivery truck at the construction site and before the concrete is poured into place at the delivery site.

In some embodiments, at least 50% of the data used for establishing the stored at least two data curves comprises jump speed data obtained at the delivery construction site but before the concrete is poured into place at the site.

According to the present invention, there is further provided a concrete monitoring system for monitoring concrete in contained within a delivery mixer truck mixer drum, the system comprising a control processor to control the monitoring and configured to perform the method described above.

Further advantages and features of some embodiments of the present invention are described in detail hereinafter.

Brief Description of Drawings

An appreciation of the benefits and features of embodiments of the invention may be more readily comprehended through consideration of the written description of example embodiments in conjunction with the drawings, wherein

Fig. 1 is a graphic illustration of the "theory of slump continuity" by which the slump of a concrete mix is presumed to be constant before and after a change in the mixer drum rotation speed and the unexpected discovery of the present inventors that two different concrete mix designs can have enormous variability after the drum speed change;

Figs. 2 and 3 are graphic illustrations of the slump behavior of two different concrete mix designs at, respectively, low mixing speed (i.e., 3 RPM as shown in Fig. 2) and at high mixing speed (i.e., 18 RPM as shown in Fig. 3) which was noted by the present inventors to show variability only at high drum mixer speed but not at low drum mixer speed; and

Fig. 4 is a block diagram flow chart to illustrate example processes of embodiments of the present invention wherein concrete slump data, obtained from automated slump monitoring systems during normal concrete delivery operations, is used to create energy or force/slump/drum-speed relationships for accurate wide speed measurements and slump (or other rheology monitoring and/or adjustment) using automated concrete mix monitoring systems.

Detailed Description of Preferred Embodiments

Embodiments of the present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which various example embodiments are shown illustrating variations within the scope of the invention. This disclosure may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete and fully convey the scope of the invention to those of ordinary skill in the art.

The term "concrete" refers to cement (which often contains pozzolanic material such as limestone, fly ash, granulated blast furnace slag) and aggregates (e.g., sand, gravel) and optionally one or more chemical admixtures (e.g., plasticizers for increasing workability, set accelerator, set retarder, air entrainer, air detrainer, plastic shrinkage reducing admixtures, corrosion inhibitors (for rebar), or other admixtures for modifying a property of the concrete, whether in its plastic or hardened state.

While automated concrete monitoring systems are known for monitoring slump, it will be understood that the present invention is applicable during the monitoring of other rheology parameters, including slump, slump flow, yield stress, viscosity, and other rheological parameters. The term "slump" is used in the present specification to illustrate conveniently any of these rheology parameters; and it should be understood that the present invention covers the monitoring of other rheology parameters even when "slump" is indicated.

The present invention sets forth a concrete monitoring calibration method for automated slump monitoring devices in near real-time across different concrete mixer drum rotation speeds and concrete mix designs in a manner that significantly reduces the number of manual slump tests required without sacrificing accuracy.

The processes of the invention may be implemented using automated concrete monitoring systems available from Verifi LLC of Cambridge, Massachusetts, USA, which are based presently on hydraulic pressure sensing and drum speed sensing. The Verifi®

technology is variously described in the patent literature (See e.g., US Patent Nos. 8764272, 8311678, 8118473, 8020431, 8746954, 8989905, 8727604, 8491717, 8764273, among others).

The present inventors also believe that the present invention could be implemented using force (or stress/strain gauge type) sensors available from Sensocrete (e.g., U.S. Publ. No. 2015/0051737 A1 of Berman) or IBB Rheology (e.g., U.S. Publ. No. 2012/0204625 A1 of Beaupre et al), both of Montreal, Canada.

Thus, the concept of energy ("E") measurement refers to an exemplary use of one or more pressure sensors for measuring the hydraulic pressure associated with rotating concrete in a truck-mounted concrete mixer drum, or, alternatively, to a force probe mounted upon an inner wall or blade of the mixer drum which emits an electrical signal corresponding to the stress exerted on the probe as it moves through concrete within the rotating drum.

It is preferred that the truck-mounted mixer drum used in combination with the automated monitoring system should have, at a minimum, at least two mixing blades spirally mounted on an inner wall of the drum which is rotatable about a non-vertical axis (e.g., at an angle with respect to level ground) and an ability to mix a volume between 0-15 cubic yards of concrete within the mixer drum. The truck should preferably have a drive means for rotating the mixer drum containing the provided concrete at a constant speed in the range of 0.5-20 RPM, one or more data memory storage locations, and one or more computer processor units for monitoring the rheology of the concrete.

The rotation speed of the mixer drum can be measured preferably using one or more of accelerometer, magnets, or rotary encoders mounted on the mixer drum, such as by using an annular arrangement of magnets passing field effect sensors, or other known means which provide an output signal to the system processor, such as Eaton sensors. An exemplary speed sensing device is a gyroscopic rotational monitoring system taught in International Publication No. WO 2015/073825A1 of Richard Jordan et al., owned by Verifi LLC.

Additionally, it is preferred that the concrete delivery truck have one or more systems for introducing water, chemical admixture, or other fluid into the concrete to adjust rheology, and that the delivery system be controlled by a processor unit in connection with the monitoring or control of concrete provided in the truck-mounted mixer drum.

Typical concrete delivery trucks allow the driver to make a speed jump (or sudden change) in the mixer drum rotational speed simply by manipulating a dial, lever, button, or other switch control within the truck cab.

A "speed jump" is illustrated as a step in Fig. 1. While the slump of the concrete remains the same before and after the change in mixer drum speed (according to the "theory of slump continuity," it is the drum speed and not the concrete that changes suddenly), it was an important discovery for the present inventors to realize that the energy value as sensed by automated concrete monitoring systems becomes unpredictable at higher mixing speeds (e.g., 6-20 RPM or more); and, moreover, that the non-linear behavior between the derived energy/force value cannot be made "linear" by a simple multiplication factor, as previously espoused by Cooley et al (as discussed in the background section).

Fig. 1 further illustrates dramatic unpredictability due to high speed mixing variability, a surprising characteristic discovered by the present inventors when examining two different concrete mix designs, both of which are presumed, according to the theory of slump continuity, to have the same constant slump value (shown by horizontal line) before and after a change in the mixer drum speed. As shown in Fig. 1, the monitored energy (E) associated with rotating two different concrete mix loads, Mix 1 and Mix 2, within a truck-mounted mixer drum, is plotted as a function of time. At the lower drum speed, the pressure value corresponding to the energy required to rotate the drum for Mix 1 and Mix 2 appears similar, as their respective energy data curves nearly coincide and overlap. However, after the sudden increase in drum speed, the sensed energy associated with rotating each of Mix 1 and Mix 2 are surprisingly different, and spaced much further apart, as compared to the curve behavior seen before the drum speed jump. The disproportionately large affect on the sensed energy on the energy/speed/slump relationship is believed by the present inventors to be due to a change in the nature and content of the aggregates, and to some extent the nature of cement in different concrete mix designs, among other concrete mix design factors (*See e.g.* Tattersall 1991).

The present inventors believe that it is important for the concrete mix to be monitored while in a non-segregated state. By "non-segregated," it is meant that the concrete is uniformly mixed so that the aggregates (e.g., sand, crushed stone) are not unevenly dispersed within the mix volume. It is also important for that the concrete mix not be dosed with a fluid (e.g., water, chemical admixture) in the moments before, during, or after the speed change or jump which is being monitored.

The concept of speed change monitoring is premised upon the present inventors' understanding that the concrete mix should be in a state of equilibrium. In other words, the mixer drum is rotated at a constant first speed for a period of time, resulting in an equilibrium output in terms of the energy required to move the concrete. After equilibrium is achieved, the drum rotation speed is changed to another speed (above or below), preferably more than one (1) RPM difference (and more preferably at least 2.5 RPM or more difference) and held at the second speed until equilibrium is again obtained. By "equilibrium," it is meant that the initial value of the output in terms of energy associated with rotation of the concrete load in the drum at a given speed does not significantly vary or differ from the output at the end of the drum revolution (e.g., beyond a pre-established or pre-selected error margin or threshold value, such as 3%, 3.5%, 4%, 4.5%, 5%, etc., which can be selected by the system programmer, manager, or user based on various factors such as sensor accuracy, mixer drum design, mixer drum drive mechanism, and others). Or described another way: the concept of "equilibrium" refers to the average output in terms of energy, if represented as a periodic wave on a video monitor, wherein the average energy value should not differ significantly between successive drum rotations (e.g., beyond a pre-established or pre-selected error margin or threshold value, as discussed above).

It is also preferred for purposes of achieving the most accurate monitoring and measurements in the present invention that the concrete build-up (e.g., concrete hardened on portion of the drum wall or blades, such as from previous deliveries) is less than one cubic yard.

Figs. 2 and 3 illustrate the slump behavior of two different concrete mix designs at different mixer drum speeds. In particular, Fig. 2 illustrates slump behavior of the two different concrete mixes at the relatively low speed of 3 RPM. At such low agitation speeds which are typical of delivery trucks during transit, the slump behavior of different concrete mix designs is similar in that the curve data is similar (for energy(E)/speed(V)/slump(S) relationship). In contrast, Fig. 3 illustrates that at high mixing speed (e.g., 18 RPM, but the present inventors believe that the curves would be similar for 12-20 RPM) the relationship between energy and slump values are substantially different. Here the energy is shown to differ by more than 200 pounds per square inch (psi). This difference in the energies associated with rotating two different concrete mix designs is much more pronounced at higher drum speeds, as compared to lower speeds (3 RPM) at which the difference was no more than 100 psi at any given point over the entire slump range from 2 to 8 inches.

From these surprising results, the present inventors realized that when viewing collected E/V/S data curves for different concrete mix designs at low and high mixing speeds, there was a long felt and desperate need for the ability of the present invention to achieve slump monitoring calibration at the higher (6-12 RPM) and highest (12-20 RPM) drum speeds, thus achieving an ability for each delivery truck to perform wide speed range monitoring, without having to perform testing (manual slump cone) for each mix design.

Thus, exemplary method of the present invention for concrete monitoring calibration using a processor-controlled system and a delivery mixer truck mixer drum, comprises:

(A) monitoring concrete provided in the mixer drum by measuring, while the concrete is in a state of equilibrium, the energy (“E1”) associated with rotating the concrete at a first constant speed (“V1”) and energy (“E2”) associated with rotating the concrete at a second constant speed (“V2”) after a speed jump of plus or minus at least 2.5 rotations per minute (RPM);

(B) calculating a slump value (“S”) for the provided concrete based on E1, V1, E2, and V2;

(C) comparing E1, V1, E2, V2, and S as calculated from step (B) with at least two data curves stored in processor-accessible memory, the stored data curves defining an E/V/S relationship for purposes of calculating slump across drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM, the at least two stored data curves comprising data obtained from previous deliveries of concrete when the previous concrete was in a state of equilibrium and comprising energy (E) values measured before and after at least 2.5 RPM jumps in constant drum speed (V) and slump values (S) as calculated from the previously stored E and V data, whereby the process-controlled system determines whether any of the at least two stored data curves match the E1, V1, E2, V2, and S values of the provided concrete; and

(D) monitoring the slump of the provided concrete in the mixer drum by calculating slump through measurement of the energy associated with rotating the concrete

(i) within 0.5 RPM - 6 RPM and within 6 RPM - 20 RPM drum speed ranges, based on one of the at least two stored data curves which is determined to constitute a match in step (C), and providing a visual indication that slump is being calculated by the system for drum speeds higher than 6 RPM; or

(ii) within the 0.5 RPM - 6 RPM range only, if none of the stored curve data is determined to constitute a match in Step (C), and initiating an alert to a system operator or the truck driver, or dispatch center, that the system is active only for monitoring at drum speeds below 6 RPM.

In further exemplary methods of the present invention, the equilibrium state of the concrete is confirmed by averaging the energy associated with rotating concrete in the mixer drum at constant speed through each of at least two successive drum rotations and determining that the average energy value does not vary over the at least two successive drum rotations, beyond a pre-established error margin value (i.e., which could be selected by the programmer); or, alternatively, by confirming that an initial value of energy associated with rotation of the concrete in the drum at a given speed does not differ from the output at the end of a complete drum rotation, beyond a pre-established error margin value.

In other exemplary methods, the mixer drum speed jump in step (A) can be effectuated by an operator of the concrete delivery truck activating a mixer drum speed switch, dial, lever, or pushbutton (i) to increase mixer drum speed from 0.5 - 6 RPM to 6 - 20

RPM or to decrease drum speed from 6 - 20 RPM to 0.5 - 6 RPM (wherein the increase or decrease is by at least 2.5 RPM); or (ii) to change drum speed by at least 2.5 RPM between two mixer drum speeds within the range of 4.5 - 20 RPM.

In further exemplary methods, the slump (S) in step (B) can be calculated using any known methods, such as (i) by rotating the provided concrete in step (A) at a drum speed whereby S1 or S2 is within the range of 0.5-6 RPM, and employing at least one stored data curve defining an E/V/S relationship wherein the speed (V) is below 6 RPM or (ii) in establishing a linear relationship for E1, V2, E2, and V3, which, if plotted as a function of drum speed (V) along a horizontal axis against energy (E) along a vertical axis, whereby the ***slope*** value of the line established by (E1, V1) and (E2, V2) and ***intercept*** value of the line which intercepts the horizontal axis (E_0 at $V = 0$) are compared to a pre-established linear relationship of slope/intercept/slump (S) values as previously stored in controller-accessible memory. The method in (i) can be used for jump speeds between low RPM drum speeds (0.5 – 6 RPM) and higher drum speeds (6 RPM to 20 RPM or even higher); whereas the method in (ii) does not necessarily require jump speeds involving lower drum speeds (below 6 RPM, such as 3-4 RPM). In the slope/intercept method (ii) mentioned above, the system process can be programmed using a linear equation based on E1, V1 and E2,V2 whereby slump (S) of provided concrete in step (A) can be predicted by using a pre-stored mathematical equation. The equation which reflects E/V/S relationship might be formulated by the system programmer, for example, based on regression analysis or using a least-squares approach to jump speed data obtained from previously sampled concrete mixes.

Thus, in exemplary methods of the invention, the slump calculation of the provided concrete in step (B) involves a change of speed involving mixer drum speed into or out of the range of 0.5 RPM - 3.5 RPM, such that a low speed curve can be used; while in other exemplary methods of the invention, it may not be necessary to use low drum speeds (< 6 RPM), but the aforementioned slope/intercept method can be used to calculate slump (S) using a pre-stored equation as desired by the monitoring system programmer or architect. The linear equation can be based, for example, on a regression analysis using the concrete customer's concrete mix designs and other factors such as the design or type of the truck or mixing drum.

In still further exemplary embodiments, the values E1, V1, E2, and V2 as measured in step (A) are stored into memory. For example, the E1, V1, E2, V2, and calculated slump (S) values can be stored into the same memory location of previously stored E/V/S curves if found to match, in order to improve the resolution or accuracy of the data curves. If a ticket is assigned to the concrete batch load, the measured E1, V1, E2, V2, and S values can be compared with any data curves previously stored in memory (library), and the monitoring system processor can be programmed to confirm that the ticketed batch conforms to at least one of the pre-stored E/V/S curve data relationships. The system processor can also be programmed to send visual confirmation to a system operator or user that the provided concrete conforms to the batch information (e.g., concrete mix identification) on the ticket.

Thus, in still further exemplary embodiments, the E1, V1, E2, and V2 values (along with any calculated slump (S) values) can be included in the previously stored curve data, such as the at least two data curves mentioned for step (C).

Once the slump of the provided concrete in step (A) is calculated in step (B), using any known method, the present invention then involves comparing the slump, in step (C), to at least two stored data curves (and more preferably to at least six data curves) defining E/V/S relationships for calculating slump across drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM. The stored data is preferably obtained from previously deliveries involving (i) mixer drums on different concrete delivery trucks; (ii) mixer drum speed jumps occurring at the delivery site before the concrete is poured into place at the site; or (iii) both (i) and (ii). More preferably, in step (C), the at least two stored data curves defining an E/V/S relationship for calculating slump across the drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM, comprise data based on mixer drum speed jumps occurring at the delivery site before the concrete is poured. And, most preferably, in step (C), the processor-accessible memory comprises at least six stored data curves define E/V/S relationships for calculating slump across the drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM; and the data of said at least six stored data curves comprise at least 50 percent of drum speed jumps occurring at the delivery site before the concrete is poured.

The at least two stored data curves which define E/V/S relationships for calculating slump across the drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM may be located in memory off of the delivery truck, such as at a dispatch center, a central office, or in the cloud. In preferred methods of the invention, a "library" of stored data curves can be downloaded from a central memory location, such as from the cloud, to controller-accessible memory on the truck (e.g., memory connected to the truck-based slump monitoring system). Hence, a library of pre-stored data curves defining E/V/S relationships for calculating slump across the drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM, can be periodically updated into each truck within a fleet, even as the various fleet trucks upload their E1, V1, E2, V2, and corresponding (calculated) slump data based on provided concretes (see Step (A)) for each delivery operation.

In still further exemplary methods, the measured energy (E) is measured using at least one hydraulic pressure sensor effective for measuring the pressure associated with rotating the provided concrete in the mixer drum, or, as previously discussed, can also be measured using a force sensor or stress gauge, mounted on the inner wall of the rotating mixer drum, as the sensor/gauge moves through the concrete being rotated in the rotated mixer drum (whereby the concrete exerts greater force on the probe as its workability decreases).

Fortunately, it is somewhat less complex when it comes to using different sensor types for monitoring during drum speed jumps. Thus, exemplary methods of the invention may employ at least one drum-mounted accelerometer, magnet, or rotary encoder for measuring drum speeds.

The methods of the present invention may be used to confirm that the rheology of the provided concrete loaded into the mixing drum conforms to the rheology behavior accordance with the batch information contained on "tickets" (paper or electronic) which is issued by the batch plant. (If the ticket is in electronic form, the batch information is downloaded into a memory location of the slump monitoring system). Accordingly, exemplary methods of the present invention further comprise: entering into controller-accessible memory the ticket batch information corresponding to the provided concrete in step (A); determining whether any of the stored at least two data curves defining E/V/S relationships for calculating slump across the drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM in step (C) are pre-assigned to the entered ticket batch information; and verifying by performing steps (C) and (D)(i) to monitor the provided concrete and to confirm that the provided concrete conforms to a data curve pre-assigned to the entered ticket batch information.

If the provided concrete does not conform to the data curve pre-assigned to the entered ticket batch information, then the system is programmed (see step (C)) to determine whether another stored data curve in processor-accessible memory matches the provided concrete. In other words, if the processor-controlled slump monitoring system does not find a matching data curve in its on-board library, then, in exemplary embodiments of the invention, the system processor can search for or retrieve a matching data curve that could be located in a remote location, such as a library of E/V/S data curves stored in the cloud, or at a remote serve location such as at the offices of the monitoring system operator or programmer, or other location.

In still further exemplary embodiments, assuming that slump of a provided concrete in step (A) is monitored before and after a speed jump, the slump of the provided concrete can be adjusting by introducing an amount of water, chemical admixture, or mixture thereof, and the amount of material introduced is based on slump calculated using jumps between the drum speed range of 0.5-6 RPM and the drum speed range of 6-20 RPM.

The present inventors further note that, if a matching stored data curve is found in step (D)(i), the system processor can be programmed to add E1, V1, E2, and V2 data as obtained in step (A), as well as the calculated slump (S) value into the matching curve data. An alert can be sent to the operator or user of the concrete monitoring system that the new data has been included in the stored curve data.

The present invention provides a concrete monitoring system configured to perform steps (A) through (D) as well as any, some, or all of the above-described exemplary methods. It may be also fair to say that the present invention provides a way for a community of concrete monitoring systems, installed on a fleet of delivery trucks, to contribute to the improvement and/or enhancement of individual monitoring system performance. This is done by allowing for the possibility of increasing the stored library of data curves for defining E/V/S relationships across the entire spectrum of mixer drum rotation speeds (0.5 to 20 RPM or more), as well as increasing the data resolution for individual data curves. In other words, the ability for each individual monitoring system to contribute E1, V1, E2, V2, and calculated S data will enhance the breadth of the data curves library as well as the accuracy of each curve data set.

While the present inventors choose to summarize the jump speed in step (A) to constitute a difference of at least 2.5 RPM (as an increase or decrease in drum speed), the actuality is that during typical concrete delivery operations, different truck drivers will change speeds according to their different habits and/or according to the nature of their trucks or mixing drum equipment. Some drivers may move their speed dial or lever from agitation speed (2-3 RPM) to the highest setting possible (e.g., 20 RPM or more), while others may prefer to jump between 12-20 RPM down to 6-9 RPM due to other considerations, such as the sound or vibration characteristics of the particular truck/drum set up. In either case, the ability of the present invention to contribute the corresponding E1/V1/E2/V2 and S data to the library of stored curve data will serve to bring the E/V/S relationships into sharper focus across the speed ranges of 0.5 RPM - 6 RPM and 6 RPM – 20 RPM (where minimum jump is at least 2.5 RPM).

Fig. 4 employs a flow chart to illustrate significant stages of an exemplary method of the invention with respect to the concrete delivery operation. At the beginning of the concrete delivery operation designated in the block at 10 in Fig. 4, a set of instructions commonly referred to as a "ticket," an electronically transmitted packet of information that could also be printed onto paper slip, is transmitted from a dispatch center to the delivery truck via communication port and electronic automated slump monitoring system. The ticket typically contains information such as the concrete mix design, the customer identity and delivery location, and preferably other information such as whether a specific slump curve exists (i.e., an existing calibration curve for predicting relationship between energy and correlated slump value at a given drum speed). The commercially available Verifi ® Slump Management System provides for this initial calibration information automatically for the convenience of its users. The ticket will usually have truck identification information (as the ticket is sent to the truck by the dispatcher who matches up the truck with the ticket).

In accordance with the present invention, the system processor on the delivery truck is programmed to detect when an abrupt change in mixing speed takes place, as designated at block 12 in Fig. 4. This jump in speed can be, for example, from a low mixing speed range (e.g., between 0.5-6 RPM) to a higher mixing speed (e.g., 6-20 RPM), and, as another example, may be a jump from high to low mixing speed. However, in any event, the difference in the speed change should preferably be at least 2.5 RPMs for purposes of data collection and monitoring using the methods of the present invention. It is noted by the present inventors that these abrupt changes in mix speed within the concrete delivery speed routine occur because it is mandatory for drivers to bring their drum speeds up to what is called "mixing speed" whenever water and/or chemical admixtures are introduced into the concrete load, but the actual "mixing speed" is usually determined by the particular concrete delivery truck manufacturer. For purposes of monitoring and compiling a curve data library in connection with implementing methods of the present invention, regardless of whether a liquid has been added ten drum rotations or two rotations before the sudden change or jump in drum speed, it is important that the concrete be at equilibrium before and after the jump speed event, otherwise the data should not be used or included in the data library for purposes of accomplishing the present invention. (*See* discussion of "equilibrium" above).

The present inventors believe that the enormous variability in the sensed energy or force values and curves, when concrete is monitored at high drum speeds (> 6 RPM and up to 20 RPM or higher) can now be viewed, in a practical sense, to amplify the sensitivity of concrete monitoring systems. The large variability in the sensed energy (or force) at high speeds, previously a cause for potential error in slump monitoring, can now be used for sensitivity in selection of the appropriate data curves derived from historical data compiled in the cloud or elsewhere in a second processor or computer system located at a remote site.

The system processor is programmed to assemble data curves which can be considered to be fairly robust in that different drum speeds can be monitored and values inputted into the system. For example, it is often the case that a given truck driver does not typically change mixer drum speed by turning the speed dial all the way to the top drum speed. Rather, the truck driver may have a personal preference for turning the speed dial to somewhere within 10-15 RPM), or may be influenced by the condition or state of the truck (e.g., the sound made by the rotating mixer drum at a given drum speed might be the factor which motivates the truck driver to set the drum speed at a certain point). Hence, the data curves which reflect the energy or force/rheology/speed correlations made by the system processor will tend to provide a complete curve profile over repeated different concrete deliveries.

It is further noted in Fig. 4 that, if the system processor detects that a jump in drum speed has occurred, as designated by block 14, wherein the change in speed meets or exceeds a limit which is pre-established by the program software (e.g., difference of at least 2.5 RPM as between first and second speed within the given low and high speed mixing ranges), then the data for both low speed and high speed is sent to an off-truck database (e.g., at a remote site or center), such as to the cloud (designated as at block 16). In other words, the data will contain the energy (pressure or force) and drum speed values (at both low and high speed), and this data will be transmitted to another processor for storing into a database (e.g., the cloud).

The monitoring system processor on the truck is also programmed to determine whether a calibration data curve (e.g., a “slump” curve or energy/slump/speed correlation) already exists, designated at block 18 in Fig. 4. If the system processor (18) determines that a slump calibration curve does not exist (e.g., the ticket does not designate an existing slump curve), then the system processor sends an alarm or alert to the system provider, manager, or architect (designated by block 26 in Fig. 4); and the processor only allows the slump system to monitor and adjust the concrete load only at low drum speeds (as designated by block 28) and preferably collects the new data (energy/drum speed) for future use by the system (block 30).

If the system processor detects that a slump curve does exist (for example, as designated in the ticket information) then the system processor is instructed by the software program to calculate slump or other rheology value (as designated at block 20) such that the slump is calculated at both high and low drum speeds.

In further embodiments, the system processor is further programmed, as shown at block 22 in Fig. 4, to confirm whether the existing slump curve preserves slump continuity by comparing the slump predicted at high speed with the existing slump curve to the slump predicted at low speed with the low-speed slump curve. Slump continuity is confirmed when these slump predictions are within a given tolerance. For example, when the drum speed is jumped from 3 RPM to 8 RPM, the slump value predicted at both of these speeds should not differ by more than one (1) inch slump value; and, more preferably, the slump value should not differ by more than one-half (1/2) inch. The tolerance should be selected by taking into consideration the sensitivity of the rheology measurement system, e.g., the hydraulic pressure sensor or force sensor (stress gauge) employed to measure the energy or forced required to rotate the concrete load at a given drum speed (or the precision of the slump cone test under ASTM C143 if this was used to make the initial calibration curves).

As illustrated by block 24 in Fig. 4, if the system processor confirms that predicted slump at high and low speeds differ by a value that *does not exceed* a programmed tolerance value (22 in Fig. 4), then the system processor will assign the data (the energy and drum speed values previously sent to the cloud or other system processor-accessible memory location, as designated in block 16) to a database for the given slump curve, so that the truck-mounted system processor, relative to the current or to subsequent concrete deliveries, can use the data as or as part of established slump curve data. The data can be used, for example, when the system processor monitors the jump speed data (as designated in block 12).

If the system processor confirms that the predicted slumps at high and low speeds differ by a value that *does exceed* a programmed tolerance value (as designated in block 22 of Fig. 4), then the system processor is programmed to send an alarm or alert to the slump monitoring system operator ("Verifi" LLC shown as example in Fig. 4) or to another designated recipient, such as a quality control manager, or other designated recipient (as designated at block 26).

Once an alarm or alert is sent to the slump monitoring system operator or other designated recipient or recipients (block 26), if an existing slump curve is not detected (block 18) or the new data is determined to exceed a given tolerance value (block 22), then the slump monitoring system is preferably programmed to search existing calibration curves (block 32) and/or to evaluate the data (block 30) obtained from prior deliveries to ascertain whether a calibration curve can be generated (block 36) or appropriated for use in high speed mixing ranges in the present delivery and assigned to the current mix design (block 38) or perhaps used for future deliveries (see e.g., block 24) and future monitoring and collection of jump speed data (blocks 12-20 and following again through flow diagram).

The present invention is described herein using illustrative examples and scenarios, and variations of the present invention might now appear practical, in light of these illustrations and descriptions, to those versed in the use of automated concrete monitoring systems. The exemplary embodiments described above have been based on using sudden speed change data and establishing a slump relationship based on energy (e.g., hydraulic pressure) or force (stress gauge) data, slump, and drum speed. Slump is thus understood as a function of the pressure and drum speed. In other exemplary embodiments, which are also based on the same assumption that the slump of the concrete stays the same throughout a given jump speed event, the rheology may be characterized or calculated using a different method whereby one plots the pressure (vertical-axis on a graph) against drum rotation speed (horizontal-axis), such that, as drum speed increases, the pressure typically increase. Hence, for a given jump speed event, one can draw a line through the two data points (for pressure), and define the slump relationship as a function of the slope of the line and intercept with the vertical-axis (e.g., Slump = Function (Slope, Intercept). The slopes and intercepts can then be used as an alternative way to group the data corresponding to different mix designs whereby it is stored, sorted, or retrieved by the slump system processor or cloud based system).

Again, the present invention is described herein using a limited number of illustrative embodiments not intended to limit the scope of the invention as otherwise described and claimed herein.

CLAIMS:

1. A method for concrete monitoring calibration using a processor-controlled system and a delivery mixer truck mixer drum, comprising:

(A) monitoring concrete provided in the mixer drum by measuring, while the concrete is in a state of equilibrium, the energy ("E1") associated with rotating the concrete at a first constant speed ("V1") and energy ("E2") associated with rotating the concrete at a second constant speed ("V2") after a speed jump of plus or minus at least 2.5 rotations per minute (RPM);

(B) calculating a slump value ("S") for the provided concrete based on E1, V1, E2, and V2;

(C) comparing E1, V1, E2, V2, and S as calculated from step (B) with at least two data curves stored in processor-accessible memory, the stored data curves defining an E/V/S relationship for purposes of calculating slump across drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM, the at least two stored data curves comprising data obtained from previous deliveries of concrete when the previous concrete was in a state of equilibrium and comprising energy (E) values measured before and after at least 2.5 RPM jumps in constant drum speed (V) and slump values (S) as calculated from the previously stored E and V data, whereby the process-controlled system determines whether any of the at least two stored data curves match the E1, V1, E2, V2, and S values of the provided concrete; and

(D) monitoring the slump of the provided concrete in the mixer drum by calculating slump through measurement of the energy associated with rotating the concrete

(i) within 0.5 RPM - 6 RPM and within 6 RPM - 20 RPM drum speed ranges, based on one of the at least two stored data curves which is determined to constitute a match in step (C), and providing a visual indication that slump is being calculated by the system for drum speeds higher than 6 RPM; or

(ii) within the 0.5 RPM - 6 RPM range only, if none of the stored curve data is determined to constitute a match in Step (C), and initiating an alert to a system operator or the truck driver, or dispatch center, that the system is active only for monitoring at drum speeds below 6 RPM.

2. The method of claim 1, wherein the equilibrium state of the concrete is confirmed by (i) averaging the energy associated with rotating concrete in the mixer drum at constant speed through each of at least two successive drum rotations and determining that the average energy value does not vary over the at least two successive drum rotations, beyond a pre-established error margin value; or (ii) by confirming that an initial value of energy associated with rotation of the concrete in the drum at a given speed does not differ from the output at the end of a complete drum rotation, beyond a pre-established error margin value.

3. The method of claim 1 or 2, wherein the mixer drum speed jump in step (A) is effectuated by an operator of the concrete delivery truck activating a mixer drum speed switch, dial, lever, or pushbutton (i) to increase mixer drum speed from 0.5 - 6 RPM to 6 - 20 RPM or to decrease drum speed from 6 - 20 RPM to 0.5 - 6 RPM; or (ii) to change drum speed by at least 2.5 RPM between two mixer drum speeds within the range of 0.5 - 20 RPM.

4. The method of any one of claims 1 to 3, wherein, in step (B), the slump (S) is calculated by

(i) rotating the provided concrete in step (A) at a drum speed whereby S1 or S2 is within the range of 0.5-6 RPM, and employing at least one stored data curve defining an E/V/S relationship wherein the speed (V) is below 6 RPM; or

(ii) establishing a linear relationship for E1, V1, E2, and V2, which, if plotted as a function of drum speed (V) along a horizontal axis against energy

(E) along a vertical axis, whereby the ***slope*** value of the line established by (E1, V1) and (E2, V2) and ***intercept*** value of the line which intercepts the horizontal axis (E_0 at V = 0) are compared to a pre-established linear relationship of slope/intercept/slump (S) values as previously stored in controller-accessible memory.

5. The method of any one of claims 1 to 4 wherein E1, V1, E2, and V2 obtained in step (A) are stored into memory.

6. The method of any one of claims 1 to 5 wherein E1, V1, E2, and V2 obtained in step (A) are stored into curve data among the at least two data curves in step (C).

7. The method of any one of claims 1 to 6, wherein, in step (B), the slump calculation involves a change of speed involving mixer drum speed into or out of the range of 0.5 RPM - 3.5 RPM.

8. The method of any one of claims 1 to 7, wherein, in step (C), the at least two stored data curves defining an E/V/S relationship for calculating slump across drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM, comprise data taken (i) from mixer drums on different concrete delivery trucks, (ii) from mixer drum speed jumps occurring at the delivery site before the concrete is poured into place at the site, or (iii) both (i) and (ii).

9. The method of claim 8, wherein, in step (C), the at least two stored data curves defining an E/V/S relationship for calculating slump across drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM, comprise data based on mixer drum speed jumps occurring at the delivery site before the concrete is poured.

10. The method of claim 9, wherein, in step (C), at least six stored data curves define an E/V/S relationship for calculating slump across drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM, and the data of said at least six stored data curves comprise at least 50 percent of drum speed jumps occurring at the delivery site before the concrete is poured.

11. The method of any one of claims 1 to 4, wherein, in step (C), the at least two stored data curves defining an E/V/S relationship for calculating slump across drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM is located in memory off of the delivery truck performing step (A).

12. The method of claim 11, further comprising downloading the at least two stored data curves defining an E/V/S relationship for calculating slump across drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM, from remote memory to controller-accessible memory located on the truck.

13. The method of any one of claims 1 to 12, wherein the measured energy (E) is measured using at least one hydraulic pressure sensor effective for measuring the pressure associated with rotating the provided concrete in the mixer drum, or is measured using a force or stress gauge effective for measuring the force associated with moving the concrete within the rotating drum.

14. The method of any one of claims 1 to 13, wherein at least one drum-mounted accelerometer, magnet, or rotary encoder is used to measure drum speed.

15. The method of any one of claims 1 to 14, further comprising entering into controller-accessible memory ticket batch information corresponding to the provided concrete in step (A); determining whether any of the stored at least two data curves defining an E/V/S relationship for calculating slump across drum speed ranges of 0.5 RPM - 6 RPM and 6 RPM - 20 RPM in step (C) are pre-assigned to the entered ticket batch information; and verifying by performing steps (C) and (D)(i) to monitor the provided concrete and to confirm that the provided concrete conforms to the data curve pre-assigned to the entered ticket batch information.

16. The method of claim 15, further comprising determining that the provided concrete does not conform to the data curve pre-assigned to the entered ticket batch

information, and employing step (C) to determine whether another stored data curve matches the provided concrete.

17. The method of any one of claims 1 to 16, further comprising the step of adjusting the slump of the concrete by introducing into the provided concrete an amount of water, chemical admixture, or mixture thereof, the amount introduced based on slump calculated using drum speed jumps between 0.5-6 RPM speed range and 6-20 RPM range.

18. The method of any one of claims 1 to 17, wherein, if a match is found in step (D)(i), the system processor adds E1, V1, E2, and V2 data as obtained in step (A) into the matching curve data, and an alert is sent to the operator or user of the concrete monitoring system that the new data has been included in the stored curve data.

19. A concrete monitoring system for monitoring concrete in contained within a delivery mixer truck mixer drum, the system comprising a control processor to control the monitoring and configured to perform the method of any one of claims 1 to 18.

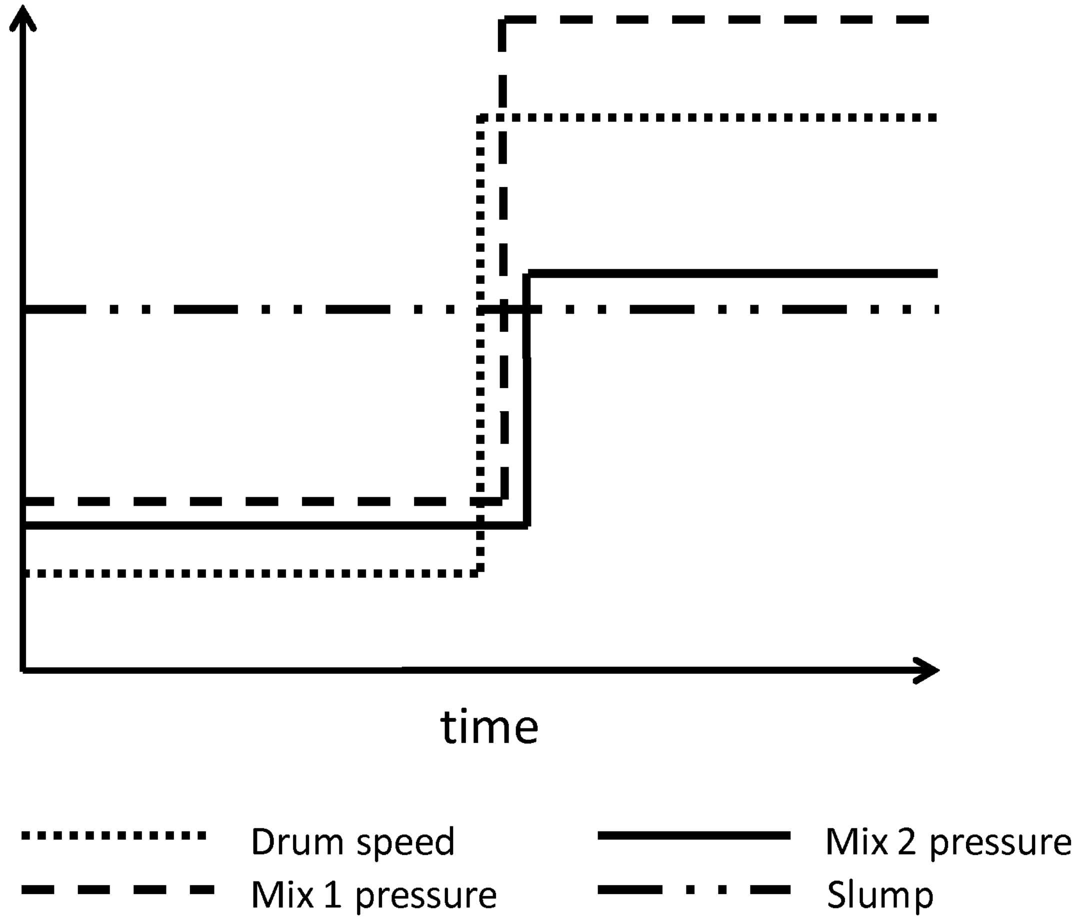


FIG.1

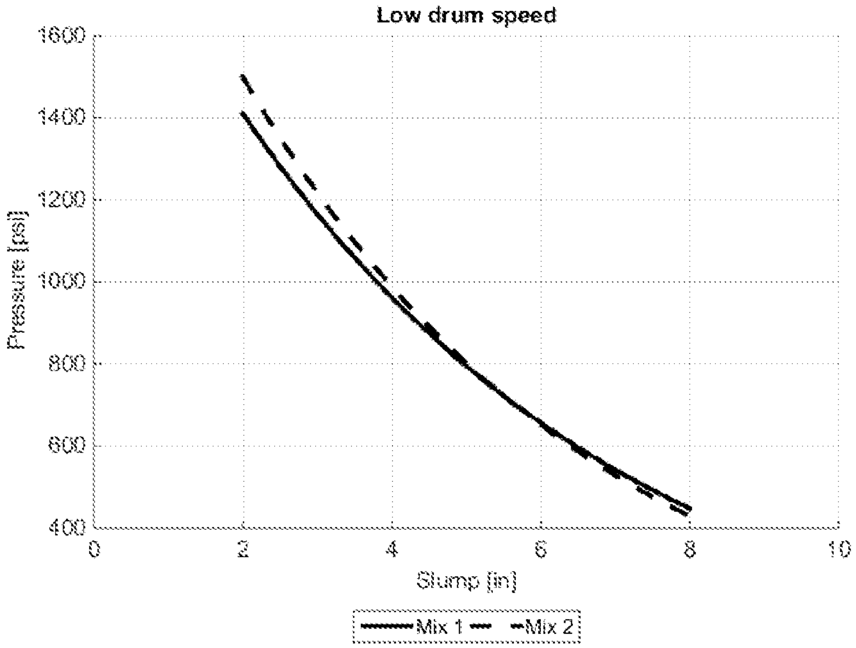

Low drum speed
1600
1400
1200
1000
800
600
400
Pressure [psi]
0
2
4
6
8
10
Slump [in]
Mix 1
Mix 2

FIG. 2

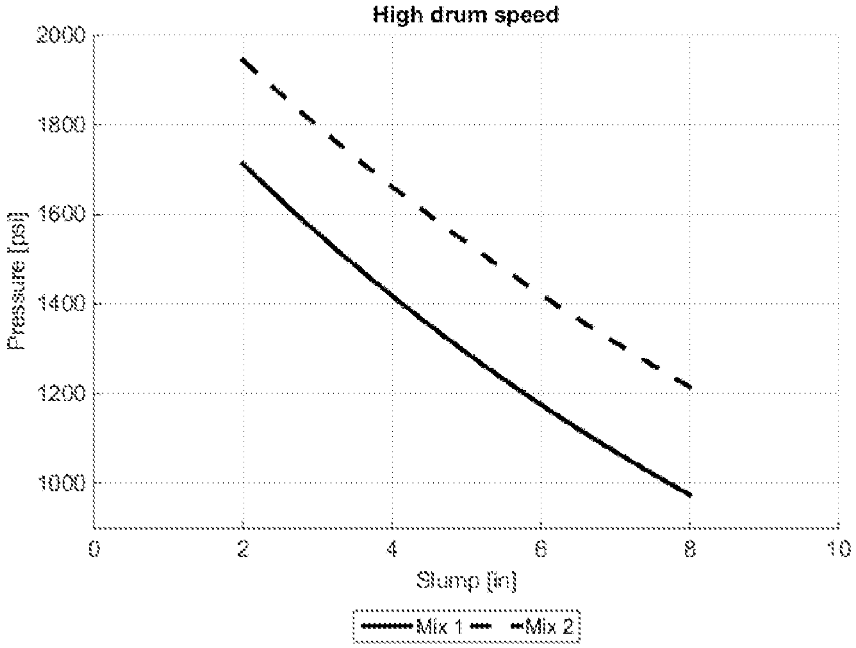

High drum speed
2000
1800
1600
1400
1200
1000
Pressure [psi]
0
2
4
6
8
10
Slump [in]
Mix 1
Mix 2

FIG. 3

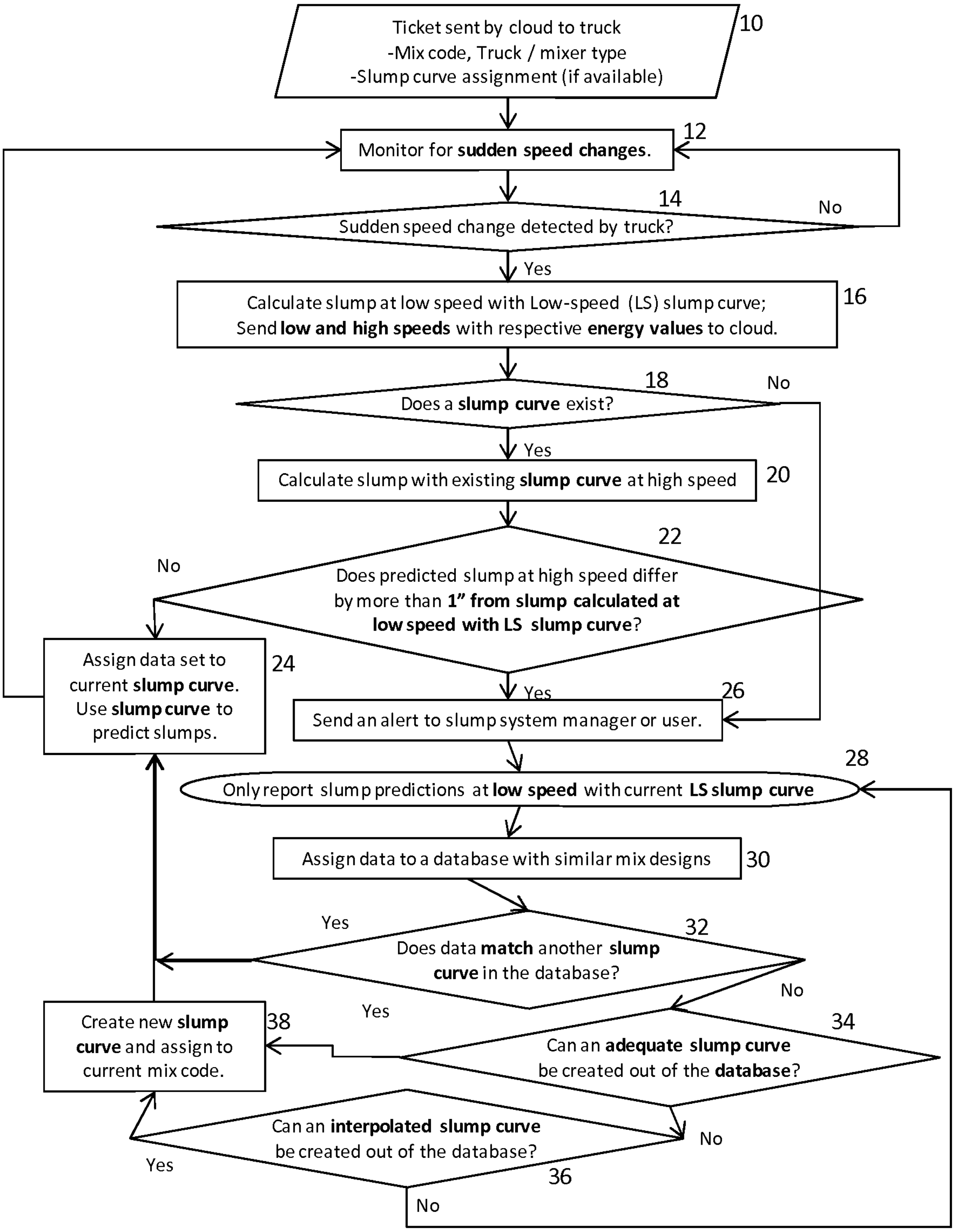
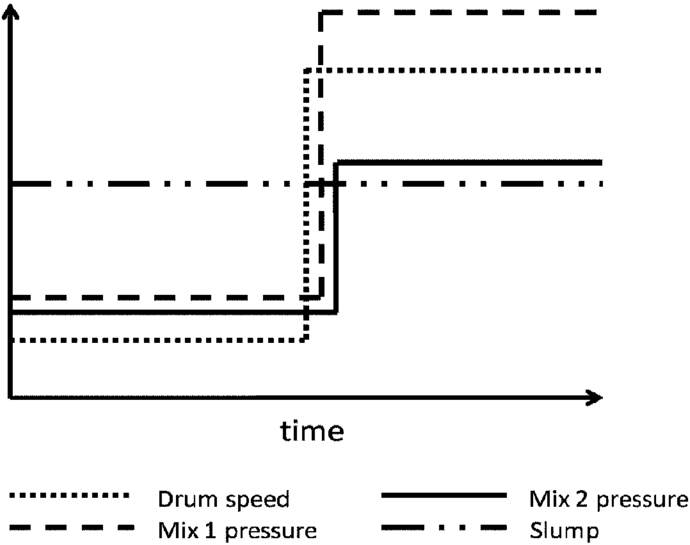

Ticket sent by cloud to truck
-Mix code, Truck / mixer type
-Slump curve assignment (if available)
10
Monitor for **sudden speed changes**.
12
14
Sudden speed change detected by truck?
No
Yes
Calculate slump at low speed with Low-speed (LS) slump curve;
Send **low and high speeds** with respective **energy values** to cloud.
16
18
Does a **slump curve** exist?
No
Yes
Calculate slump with existing **slump curve** at high speed
20
22
No
Does predicted slump at high speed differ by more than **1" from slump calculated at low speed with LS slump curve**?
Assign data set to current **slump curve**. Use **slump curve** to predict slumps.
24
Yes
26
Send an alert to slump system manager or user.
28
Only report slump predictions at **low speed** with current **LS slump curve**
Assign data to a database with similar mix designs
30
Yes
32
Does data **match** another **slump curve** in the database?
No
Yes
Create new **slump curve** and assign to current mix code.
38
34
Can an **adequate slump curve** be created out of the **database**?
Can an **interpolated slump curve** be created out of the database?
No
Yes
36
No

FIG. 4


time
Drum speed
Mix 1 pressure
Mix 2 pressure
Slump