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(54) TIRE WEAR MEASURING APPARATUS USING ACCELERATION PEAK VALUE OF TIRE AND TIRE WEAR MEASURING METHOD USING SAME

VORRICHTUNG ZUR MESSUNG DES REIFENVERSCHLEISSES UNTER VERWENDUNG DES SPITZENWERTES DER BESCHLEUNIGUNG EINES REIFENS UND VERFAHREN ZUR MESSUNG DES REIFENVERSCHLEISSES UNTER VERWENDUNG DERSELBEN

APPAREIL DE MESURE D'USURE DE PNEU UTILISANT LA VALEUR MAXIMALE D'ACCÉLÉRATION DU PNEU ET PROCÉDÉ DE MESURE D'USURE DE PNEU L'UTILISANT

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(56) References cited:
EP-A1- 2 172 760
WO-A1-2017/156213
WO-A1-2020/054658
JP-A- 2013 169 816
JP-A- 2019 127 253

EP 3 800 072 B1

Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a tire wear measuring apparatus using an acceleration peak value of a tire and a tire wear measuring method using the same, and more particularly, to a technique for measuring a wear rate of a tire tread using tendency of an acceleration peak value of a tire.

Description of the Related Art

[0002] Among the components of a vehicle, tires are the only component contacting a road surface and directly related to the vehicle's turning and braking performance. If tires are worn, the turning and braking performance may not be properly implemented. Thus, worn tires may be directly related to the vehicle's safety. Specifically, if a braking distance on a wet road surface increases due to the wear of the tire, it may directly lead to a vehicle accident.

[0003] Accordingly, research and development of a system which measures the wear rate of tire tread and the like in real time and automatically informs the replacement time of tires according to the wear rate of tires are being actively conducted.

[0004] In U.S. Patent Application Publication No. 2017-0113495 (Title: Indirect tire wear state estimation system), load of a vehicle is inferred and then a wear rate according to a distance travelled is estimated based on the load of the vehicle. However, it is inefficient since information on too many factors is required to estimate the wear rate. In addition, in U.S. Patent No. 8,483,976 (Title: Method for estimating tire wear and apparatus for estimating tire wear) and U.S. Patent No. 8,061,191 (Title: Method and apparatus for detecting wear of tire), a wear rate of a tire is measured by a method using sensing of a tire. However, it is difficult to expect consistent results. Further, actual vehicle operating conditions are not considered, resulting in a limitation in determining accurate tire wear under actual conditions.

Citation List

Patent Literature

[0005]

Patent Literature 1: US Patent Application Publication No. 2017-0113495
Patent Literature 2: U.S. Patent No. 8,483,976
Patent Literature 3: U.S. Patent No. 8,061,191

SUMMARY OF THE INVENTION

[0006] According to an embodiment an acceleration signal of a tire is measured using an acceleration sensor, and to measure the wear amount of a tire tread by analyzing the acceleration signal.

[0007] The technical objects to be achieved by the provided embodiments are not limited to as described-above, and other technical objects which are not described will be clearly understood by a person who has ordinary knowledge in the technical field of the art.

[0008] A configuration of the present invention for achieving the above objects includes: a signal receiver configured to measure acceleration inside a tire installed to a vehicle for each point inside the tire; a signal analyzer configured to receive signal information from the signal receiver and estimate a tread wear rate of the tire using a peak value of acceleration in longitudinal direction perpendicular to an axial direction of the tire from among acceleration signals inside the tire; a transmitter configured to receive analysis information, which is information on the tread wear rate of the tire, from the signal analyzer and transmit the analysis information; and a control module configured to receive the analysis information from the transmitter and generate a control signal for the vehicle to which the tire is installed. A peak value of acceleration is acquired when the signal receiver measures acceleration of a grounding portion where the tire contacts a road surface.

[0009] The signal analyzer is configured to apply the peak value of acceleration to the following equation acquired through normalization, which excludes influence of speed, load, and pressure of the tire, to derive a tread thickness of the tire, thereby estimating and calculating a tread wear rate of the tire.

$$f_h(\mathrm{h}) = \frac{Acc_x}{\Omega^2 \theta_r^\alpha}$$

[0010] In an embodiment, data on α, which is the unique constant value for the tire, may be preset and stored in the signal analyzer.

[0011] In an embodiment, the control module may include a vehicle controller configured to control the vehicle and an information transmitter configured to receive the analysis information from the transmitter and transmit the analysis information to the vehicle controller. The vehicle controller may be further configured to determine a replacement time of the tire using the analysis information.

[0012] In an embodiment, the control module may further include a display configured to display the replacement time of the tire or information on a service of replacing the tire.

[0013] A tire wear measuring method using a tire wear measuring apparatus according to the present invention is defined in claim 5.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014]

FIG. 1 is a schematic diagram of a configuration of a tire wear measuring apparatus according to an embodiment;
FIG. 2 is a schematic diagram of a shape of a tire when contacting a road surface and a graph of an acceleration signal according to an embodiment;
FIG. 3 is a graph comparing a change in peak value of an acceleration signal of a tire according to a tread wear amount (mm) of the tire according to an embodiment;
FIGS. 4 to 6 are graphs comparing a change in peak value of acceleration of a tire according to a change in speed, load, and pressure of the tire according to an embodiment;
FIG. 7 is a graph showing a result of curve-fitting a peak value of longitudinal acceleration of a tire according to an embodiment;
FIG. 8 is a graph for comparing of peak values of acceleration according to a wear amount of a tire according to an embodiment;
FIG. 9 is a graph showing a result of curve-fitting a peak value of acceleration by an actual signal obtained from an acceleration sensor according to an embodiment;
FIG. 10 is a graph showing tendency of a normalized peak value of acceleration according to tread wear of tire according to an embodiment; and
FIG. 11 is a graph comparing tendency of a peak value of acceleration and an actual wear amount of the tire according to an embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0015] Hereinafter, embodiments will be described with reference to the accompanying drawings. However, embodiments may, e.g., be implemented in various different forms and is not limited to the embodiments described herein. To clearly describe embopdiments, parts irrelevant to the description will be omitted in the drawings, and like elements will be designated by like numerals throughout the specification.

[0016] In this specification, when a part is referred to as being "connected" to another part, it may not only be "directly connected" but also may be "electrically connected" to the other part via an element disposed therebetween. Also, when a part is referred to as "including" an element, this means that the part does not exclude another element and may further include another element unless stated otherwise.

[0017] The terminology used herein is merely for the purpose of describing particular embodiments and is not intended to limit the invention. A singular form is intended to include a plural form as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, components, and/or combinations thereof but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or combinations thereof.

[0018] Hereinafter, embodiments will be described in detail with reference to the accompanying drawings.

[0019] FIG. 1 is a schematic diagram of a configuration of a tire wear measuring apparatus according to an embodiment. As shown in FIG. 1, a tire wear measuring apparatus includes: a signal receiver 110 for measuring acceleration inside a tire installed to a vehicle for each point inside the tire; a signal analyzer 120 for receiving signal information from the signal receiver 110 and estimating a tread wear rate of the tire using a peak value of acceleration in longitudinal direction perpendicular to an axial direction, which is the radial direction of the tire, among acceleration signals inside the tire; a transmitter 130 for receiving analysis information, which is information on the tread wear rate of the tire, from the signal analyzer 120 and transmitting the analysis information; and a control module 200 for receiving the analysis information from the transmitter 130 and generating a control signal for the vehicle to which a tire is installed. The peak value of acceleration may be acquired when the signal receiver 110 measures acceleration of a grounding portion where the tire contacts a road surface.

[0020] Here, a measurement module 100 may be formed by combining the signal receiver 110, the signal analyzer 120, and the transmitter 130, and the measurement module 100 may be formed by being connected to each tire installed to the vehicle or may be formed by being connected to every tire installed to the vehicle.

[0021] In addition, the control module 200 includes a vehicle controller 210 for controlling a vehicle and an information transmitter 220 for receiving analysis information from the transmitter 130 and transmitting the received analysis information to the vehicle controller 210, and the vehicle controller 210 may determine a tire replacement time using the analysis information. In addition, the control module 200 may further include a display 230 for displaying a tire replacement time or information on a service of replacing the tire.

[0022] The signal receiver 110 may include a plurality of acceleration sensors, and each of the plurality of acceleration sensors may measure acceleration in an axial direction of each of a plurality of points inside a tire tread. Further, a number may be sequentially assigned to each acceleration sensor, and accordingly, measurement signals measured by the respective acceleration sensors may be sequentially collected and converted into data. In addition, in response to receiving analysis information, the transmitter 130 may transmit the analysis information to the information transmitter 220 of the control module 200 wirelessly or by wire. To this end, the information transmitter 220 may be connected to the transmitter 130 wirelessly or by wire.

[0023] The vehicle controller 210 may be wirelessly connected to an integrated control system outside the vehicle while controlling the vehicle. In the vehicle controller 210, replacement time information, which is information on a scheduled tire replacement time according to a tire wear rate, may be stored in advance, and the vehicle controller 210 may compare the replacement time information with the tire wear rate in real time to determine information on a remaining time for tire replacement, the tire replacement time, and the like. In addition, the vehicle controller 210 may transmit the information on the remaining tile for tire replacement, the tire replacement time, and the like to the integrated control system. Using the information transmitted from the vehicle controller 210, the integrated control system may transmit, to the vehicle controller 210, information on a tire replacement service such as a quantity of tires stocked at a replacement time of a tire installed to the vehicle, a tire replacement repair center, and the like. The vehicle controller 210 may transmit the information on the tire replacement service to the display 230, and such information may be displayed on the display 230. In addition, even the information on the remaining time for tire replacement and the tire replacement time, which is generated by the vehicle controller 210, may also be displayed on the display 230 and informed to a user.

[0024] Hereinafter, a process of deriving an equation for estimating a tread wear rate of a tire by the signal analyzer 120 will be described.

[0025] FIG. 2 is a schematic diagram of a shape of a tire when contacting a road surface and a graph of an acceleration signal according to an embodiment. Specifically, in FIG. 2, an upper schematic diagram illustrates a deformed tire, and a lower schematic diagram is a graph of an acceleration signal generated by rotation of the tire. As shown in FIG. 2, a longitudinal acceleration signal may form a peak value at both ends of a grounding portion of the tire in contact with a road surface. That is, it can be said that such a peak value of longitudinal acceleration reflects grounding characteristics of the tire and the road surface and property characteristics of the tire near the grounding.

[0026] As described above, since the acceleration sensor is formed at each point inside the tread of the tire to measure the acceleration signal of the tire and the tire wear measuring apparatus uses a peak value of acceleration, the signal analyzer 120 may use an acceleration signal transmitted from an acceleration sensor formed adjacent to a grounding portion of the tire with respect to a road surface among acceleration signals received from the signal receiver 110 or may use an acceleration signal received from an acceleration sensor which generates a greatest signal among acceleration sensors formed adjacent to the grounding portion of the tire with respect to the road surface.

[0027] It is possible to analyze a change in tendency of a peak value of longitudinal acceleration of a tire according to an increase in wear rate of the tire based on two changes in condition of the tires that appear according to the wear of the tires. A first change in condition of a tire due to wear of the tire may be a change in bending stiffness of the tire. As the wear of the tire increases, a tread thickness of the tire decreases, and accordingly, the bending stiffness of the tire may decrease. The decrease in the tread bending stiffness of the tire due to the wear of the tire may cause a greater deformation of the tire at a grounding portion (area) of the tire.

[0028] FIG. 3 is a graph for comparing a change in peak value of an acceleration signal of a tire according to a tread wear amount (mm) of the tire according to an embodiment. In FIG. 3, the horizontal axis represents rotation (deg) of the tire, and the vertical axis represents longitudinal acceleration. Specifically, FIG. 3 is a graph regarding an acceleration signal generated upon rotation of a tire through a Flexible Ring tire model, and a change in acceleration signal peak value according to a tread wear amount of each tire may be compared using the graph. At this point, analysis of the

Flexible Ring tire model may be performed using a computer programs such as Python or Matlab, etc., and the analysis of the Flexible Ring tire model may be performed through simulation using the computer program. In addition, the trend of a mathematical model may be verified using a FEM program such as ANSYS, NASTRAN, and ABAQUS. Hereafter, it is the same.

[0029] In FIG. 3, graph a is a graph for a case where there is no tread wear amount of a tire, graph b is a graph for a case where a tread wear amount of the tire is 2 mm, graph c is a graph for a case where a tread wear amount of the tire is 4 mm, and graph d is a graph for a case where a tread wear amount of the tire is 6 mm. As shown in FIG. 3, it can be seen that as wear of the tire progresses, bending stiffness of the tire decreases, and as a result, deformation increases at a grounding portion of the tire. This may mean that a change in curvature occurs at both ends of the grounding portion of the tire.

[0030] In conclusion, as tread wear of the tire increases, a longitudinal acceleration signal peak value may increase at both ends of the grounding portion of the tire with respect to a road surface. Such a decrease in bending stiffness due to wear of the tire may cause a greater deformation of the tire at the grounding portion of the tire, which may mean that the change in curvature at both ends of the grounding portion of the tire is increased. As the wear of the tire increases, a longitudinal acceleration signal at both ends of the grounding portion, that is, a peak value of longitudinal acceleration may increase.

[0031] Further, on the other hand, in the case of the second change in condition of a tire, as wear of the tire increases, a tread mass of the tire decreases, and a tread stiffness of the tire may increase. In addition, as the tread stiffness of the tire increases, a tread natural frequency of the tire may increase. In addition, when the tire is rotating, the road surface which has been in contact with the grounding portion of the tire may be momentarily released from the contact. At this point, assuming that the tread of the tire is a mass-spring damper system in a simple shape, there is a tendency that as a natural frequency of the system increases, an instant acceleration increases. Thus, as the tread wear of the tire progresses, the tread natural frequency of the tire may increase and, as a result, a longitudinal acceleration signal value at both ends of the grounding portion of the tire may increase. This is clear from the result in FIG. 3. As shown in FIG. 3, as a result of comparing the peak value of longitudinal acceleration signal according to a wear of the tire through Flaxible Ring tire model, it can be found that the peak value of longitudinal acceleration of the tire increases as the wear of the tire increases.

[0032] However, even if the peak value of acceleration changes according to the progress of the wear of the tire as described above, there are many limitations in using the peak value of longitudinal acceleration as a factor for estimating the wear of the tire.

[0033] FIGS. 4 to 6 are graphs comparing a change in peak value of acceleration of a tire according to a change in speed, load, and pressure of the tire according to an embodiment. In FIGS. 4 to 6, the horizontal axis represents rotation (deg) of a tire, and the vertical axis represents longitudinal acceleration. Specifically, FIG. 4 is a graph showing a change in peak values of acceleration of a tire according to a change in speed of the tire. In FIG. 4, graph a is a graph for a case where the speed of the tire is 30 km/h (kph), graph b is a graph for a case where the speed of the tire is 65 km/h (kph), and graph c is a graph for a case where the speed of the tire is 100 km/h (kph).

[0034] In addition, FIG. 5 is a graph showing a change in peak values of acceleration of a tire according to a change in load of the tire. In FIG. 5, graph a is a graph for a case where the load of the tire is 5000N, graph b is a graph for a case where the load of the tire is 6000N, the graph c is a graph for a case where the load of the tire is 7000N, and graph d is a graph for a case where the load of the tire is 8000N.

[0035] In addition, FIG. 6 is a graph showing a change in peak values of acceleration of a tire according to a change in pressure of the tire. In FIG. 6, graph a is a graph for a case where the load of the tire is 1.5 bar, graph b is a graph for a case where the load of the tire is 1.7 bar, graph c is a graph for a case where the load of the tire is 1.9 bar, and graph d is a graph for a case where the load of the tire is 2.1 bar.

[0036] As shown in FIGS. 4 to 6, since the peak value of longitudinal acceleration in the tire is greatly affected by the speed, load, and pressure of the tire, it is necessary to remove influence of the speed, load, and pressure of the tire in order to check only the influence of the wear of the tire on the peak value of acceleration.

[0037] Accordingly, the peak value of longitudinal acceleration of the tire may be determined as a signal characteristic according to wear of the tire by removing the influence of the speed, load, or pressure of the tire based on the Flaxible Ring tire model. The following [Equation 1] may express the peak value of longitudinal acceleration of the tire.

[Equation 1]

$$Acc_x = f_0(\Omega, F_z, p_0, h)$$

[0038] Here, Acc_x is a peak value of acceleration, h is a tread thickness of the tire, Ω is an angular velocity of the tire, p_0 is pressure of the tire, and F_z is load of the tire. Hereinafter, it is the same.

[0039] In [Equation 1], normalization of an angular velocity (velocity) may be performed for peak values of the same longitudinal acceleration, and theoretically, longitudinal acceleration based on the Flexible Ring tire model may be expressed as [Equation 2].

[Equation 2]

$$\ddot{v} = \frac{d^2 v}{dt^2} = \frac{d\theta}{dt}\frac{d^2 v}{d\theta dt} = \left(\frac{d\theta}{dt}\right)^2 \frac{d^2 v}{d\theta^2} = \Omega^2 v''$$

[0040] Here, v may be an amount of change in a longitudinal distance vector of a tire.

[0041] In addition, assuming that there is no damping effect due to rotational resistance inside the tire in the Flexible Ring tire model, the longitudinal acceleration of the tire may have a constant value even if the angular velocity of the tire changes. Accordingly, the peak value of longitudinal acceleration of the tire may be expressed as [Equation 3].

[Equation 3]

$$Acc_x = f_0(\Omega, F_z, p_0, h) = \Omega^2 f_1(F_z, p_0, h)$$

[0042] Here, the coefficients and characters represent the same as the coefficients and characters used in the above equations.

[0043] In addition, it is possible to more simply define [Equation 3] using three assumptions, and the three assumptions may be as follows.

Assumption 1: (F_z, p_0) and h_0 are independent.
Assumption 2: $f_2(F_z,p_0) = f_\theta(\theta_r)$
Assumption 3 : $f_\theta(\theta_r) = C\theta_r^\alpha$

[0044] That is, load F_z and pressure p_0 of the tire and an initial tread thickness h_0 of the tire are defined as independent variables (Assumption 1) ; a function $f_2(F_z,p_0)$ of the load F_z and pressure p_0 of the tire is replaced with a function $f_\theta(\theta_r)$ of an angular velocity θ_r of the tire (Assumption 2), and a function $f_\theta(\theta_r)$ of angular velocity θ_r of the tire may be defined as a function $C\theta_r^\alpha$. Here, α is a unique constant value for the tire and C is a constant value. Hereafter, it is the same.

[0045] As a result, [Equation 3] may be expressed as [Equation 4] below.

[Equation 4]

$$Acc_x = \Omega^2 \theta_r^\alpha f_h(\mathbf{h})$$

[0046] In order to verify [Equation 4] which is an equation for longitudinal acceleration of a tire expressed relatively simply by the above assumptions, a simulation using a Flexible Ring tire model is performed. At this time, the influence of the tire speed on the peak value of longitudinal acceleration of the tire is removed from an influence map as shown in [Equation 4]. As an actual acceleration signal by an acceleration sensor installed at the tire may also be found, after fixing the speed at 65 km/h, a simulation is conducted for conditions in which a wear amount (0-6mm), pressure (1.5 bar-2.1 bar), and load (5000-8000N) of the tire change.

[0047] FIG. 7 is a graph showing a result of curve-fitting a peak value of longitudinal acceleration of a tire according to an embodiment. In FIG. 7, graph a is a graph for a condition in which the wear amount of the tire is set to 0 mm and the pressure and load of the tire change; graph b is a graph for a condition in which the wear amount of the tire is set to 2 mm and the pressure and load of the tire change; graph c is a graph for a condition in which the wear amount of the is set to 4 mm and the pressure and load of the tire change; and graph d is a graph for a condition in which the wear amount of the tire is set to 6 mm and the pressure and load of the tire change. Here, the horizontal axis (x-axis) represents a contact angle of an end of a grounding portion of the tire, and the vertical axis (y-axis) represents a peak value of longitudinal acceleration of the tire.

[0048] Finally, if curve-fitting of a peak value of longitudinal acceleration value obtained through the above simulation is performed by [Equation 4], a result thereof may be as shown in FIG. 7. In addition, it may be found that the peak value of longitudinal acceleration is well-fitting for all conditions. These results show that [Equation 4], which expresses a peak value of longitudinal acceleration, well describes an actual value. That is, it may be found that [Equation 4] assumed above is experimentally verified through a Flexible Ring tire model. The expression of the peak value of longitudinal acceleration as shown in [Equation 4] may be actively used to process the peak value of longitudinal acceleration measured using the acceleration sensor of the tire as a factor for estimating wear of the tire.

[0049] FIG. 8 is a graph for comparing peak values of acceleration according to a wear amount of a tire according to an embodiment. Specifically, FIG. 8 is a graph for comparing peak values of longitudinal acceleration according to a wear amount of a tire through an actual experiment. In FIG. 8, the horizontal axis represents rotation (deg) of the tire, and the vertical axis represents longitudinal acceleration. It is analyzed whether tendency of a peak value of longitudinal acceleration of a tire according to wear analyzed through Flexible Ring tire model is observed in an actual tire acceleration signal, and furthermore, a process for using the peak value of longitudinal acceleration of the tire as a factor for estimating wear of the tire is performed. As shown in FIG. 8, it may be found that, in actual data, the peak value of longitudinal acceleration measured using an actual tire according to wear of the tire tread has a great tendency with wear of the tire.

[0050] As shown in FIG. 8, the peak value of longitudinal acceleration of the tire may be affected by the speed, load, or pressure of the tire, similarly to the Flexible Ring tire model. Therefore, it may be necessary to remove such influence. Normalization, which is a necessary process, may be performed based on the following [Equation 5], and the peak value of longitudinal acceleration of the tire may be expressed as a function of an angular velocity Ω, a contact angle θ_r, and a thickness h of the tire. In other words, an equation such as [Equation 5] may be derived through an equation assumed from the above model.

[Equation 5]

$$f_h(\mathbf{h}) = \frac{Acc_x}{\Omega^2 \theta_r^{\alpha}}$$

[0051] Here, f_h(h) is a function in which factors for the speed, load, and pressure of the tire are removed from a tire acceleration signal function. The remaining coefficients and characters represent the same coefficients and characters used in the above equations.

[0052] If a value of a factor α determined according to a tire is known in [Equation 5], the tread thickness h of the tire, that is, a function related only to tire wear (left side) may be extracted. Then, the signal analyzer 120 may apply the peak value of acceleration to [Equation 5], which is obtained through normalization of removing influence of speed, load, and pressure of the tire, to derive the thickness of the tread of the tire, thereby calculating and estimating a tread wear rate of the tire. Specifically, the tread wear rate of the tire may be calculated and estimated by comparing and calculating a decrease in thickness of the tread of the tire and an initial thickness of the tread of the tire. In addition, data for α, which is a unique constant value for the tire, may be preset and stored in the signal analyzer 120.

[0053] FIG. 9 is a graph showing a result of curve-fitting a peak value of acceleration by an actual signal obtained from an acceleration sensor according to an embodiment. A value of α may be derived using [Equation 5] based on an acceleration signal from an acceleration sensor of an actual tire. As described above, the value of α is set as the tire's unique factor and may be stored in advance in the signal analyzer 120.

[0054] FIG. 10 is a graph showing tendency of a normalized peak value of acceleration according to tread wear of tire according to an embodiment, and FIG. 11 is a graph comparing tendency of a peak value of acceleration and an actual wear amount of the tire according to an embodiment. In FIG. 10, the horizontal axis may represent an actual tread wear amount (mm) of the tire, and the vertical axis may represent a normalized longitudinal peak. In addition, in FIG. 11, the vertical axis may represent a wear amount (mm) calculated using the Flexible Ring tire model, and the horizontal axis may represent an actual amount of wear (mm) of the tire tread.

[0055] As shown in FIGS. 10 and 11, peak values of the newly defined and normalized longitudinal acceleration are applied/analyzed for various conditions. Specifically, while changing pressure, load, velocity, and the like of a tire, comparative analysis is conducted for a total of 12 conditions (3 load conditions x 4 pressure conditions) for each tire wear stage. Here, each point shows the results of various conditions, and each solid line may be a graph formed by connecting the average value of each point for each amount of wear.

[0056] As shown in the results of FIGS. 10 and 11, it may be found that as the tread wear of the tire increases, the normalized peak value of longitudinal acceleration tends to continuously increase.

[0057] Through the above process, the peak value of longitudinal acceleration according to the wear of the tire is normalized, and the tendency of the peak value of acceleration according to the wear of the tire is analyzed. As a result, it is found that as the wear of the tire progresses, the normalized peak value of longitudinal acceleration tends to decrease both in the simulation and experiment.

[0058] Specifically, in the case where wear of the tire is estimated based on the normalized peak value of longitudinal acceleration and performance resulting therefrom is evaluated, when the wear of the tire is estimated based only on the normalized peak value of longitudinal acceleration, it is found that the same performance as in FIGS. 10 and 11 is achieved. The tendency of the normalized peak value of longitudinal acceleration shows a nearly constant slope regardless of a wear level of the tire tread, and thus, it is found that similar estimation performance is achieved at any wear level.

[0059] According to the above configuration, it is possible to measure an acceleration signal of a tire using an acceleration sensor, extract a peak value of acceleration of the tire from the acceleration signal, and estimate a tread wear rate of the tire by analyzing the peak value, and therefore, a wear amount of the tire may be measured in real time. In addition, it is possible to share information on the wear amount of the tire not only with a vehicle user but also with an integrated control system, and therefore, an automatic service for replacement of the tire may be implemented.

[0060] Hereinafter, a method for measuring wear of the tire using a tire wear apparatus will be described.

[0061] In a first step, acceleration inside a tire with respect to a longitudinal direction may be determined for each point inside the tire. In a second step, a tread wear rate of the tire may be estimated by using a peak value of acceleration in the longitudinal direction perpendicular to the axial direction, which is the radial direction of the tire, among acceleration signals inside the tire. Next, in a third step, a replacement time of the tire may be determined using information on the tread wear rate of the tire. Then, in a fourth step, information on the replacement time of the tire may be transmitted to a user of the vehicle and an external integrated control system connected to the vehicle.

[0062] A description on what is not described in relation to the tire wear measuring method using the tire wear measuring apparatus may be the same as the above description about the tire wear measuring apparatus according to an embodiment.

[0063] Embodiments according to the configuration as described above have advantageous effects that it is possible to measure an acceleration signal of the tire using an acceleration sensor, extract a peak value of acceleration of the tire from the acceleration signal, and estimate a tread wear rate of the tire through analysis of the peak value, thereby estimating a wear amount of the tire in real time.

[0064] In addition, as information on a wear amount of the tire is shared not only with a user of a vehicle but also with an integrated control system, it is possible to implement an automatic service for replacement of the tire.

[0065] The effects according to embodiments are not limited to the above-mentioned effects, and it should be understood that the effects according to embodiments include all effects that can be inferred from the configuration of the invention described in the detailed description of the invention or the appended claims.

[0066] The above description of the example embodiments is provided for the purpose of illustration, and it would be understood by those skilled in the art that various changes and modifications may be made without changing the technical conception and essential features of the embodiments. Thus, it is clear that the above-described embodiments are illustrative in all aspects and are not limiting. For example, each component described to be of a single type can be implemented in a distributed manner. Likewise, components described to be distributed can be implemented in a combined manner.

[0067] The scope of the inventive concept is defined by the following claims.

Claims

1. A tire wear measuring apparatus using an acceleration peak value of a tire, the apparatus comprising:

    a signal receiver (100) configured to measure acceleration inside a tire installed to a vehicle for each point inside the tire;
    a signal analyzer (120) configured to receive signal information from the signal receiver (100) and estimate a tread wear rate of the tire using a peak value of acceleration in longitudinal direction perpendicular to a radial direction of the tire from among acceleration signals inside the tire;
    a transmitter (130) configured to receive analysis information, which is information on the tread wear rate of the tire, from the signal analyzer and transmit the analysis information; and
    a control module (200) configured to receive the analysis information from the transmitter (130) and generate a control signal for the vehicle to which the tire is installed,
    wherein the peak value of acceleration is acquired when the signal receiver (110) measures acceleration of a grounding portion where the tire contacts a road surface;
    the tire wear measuring apparatus being **characterised, in that**
    the signal analyzer (120) is configured to apply the peak value of acceleration to the following equation obtained

through normalization, which excludes influence of speed, load, and pressure of the tire, to derive a tread thickness of the tire to estimate and calculate a tread wear rate of the tire:

$$f_h(\mathrm{h}) = \frac{Acc_x}{\Omega^2 \theta_r^\alpha}$$

where Acc_x is a peak value of acceleration, h is the tread thickness of the tire, Q is an angular velocity of the tire, θ_r is a contact angle between the tire and the road surface, α is a unique constant value for the tire, f_h(h) is a function obtained by removing factors for the speed, load, and pressure of the tire from an acceleration signal function of the tire.

2. The tire wear measuring apparatus of claim 1,
wherein data on α, which is the unique constant value for the tire, is preset and stored in the signal analyzer.

3. The tire wear measuring apparatus of claim 1,
wherein the control module (200) comprises:

a vehicle controller (210) configured to control the vehicle; and
an information transmitter (220) configured to receive the analysis information from the transmitter and transmit the analysis information to the vehicle controller,
wherein the vehicle controller (210) is configured to determine a replacement time of the tire using the analysis information.

4. The tire wear measuring apparatus of claim 1,
wherein the control module (200) further comprises a display (230) configured to display the replacement time of the tire or information on a service of replacing the tire.

5. A tire wear measuring method using the tire wear measuring apparatus of claim 1, comprising:

a first step in which the acceleration in a longitudinal direction is determined for each point inside the tire;
a second step in which a tread wear rate of the tire is estimated using a peak value of the acceleration in the longitudinal direction perpendicular to the radial direction of the tire, among acceleration signals inside the tire;
a third step in which a replacement time of the tire is determined using information on the tread wear rate of the tire; and
a fourth step in which information on the replacement time of the tire is transmitted to a user of the vehicle and an external integrated control system connected to the vehicle.

Patentansprüche

1. Eine Reifenverschleißmessvorrichtung, die einen Beschleunigungsspitzenwert eines Reifens verwendet, wobei die Vorrichtung folgende Merkmale aufweist:

einen Signalempfänger (100), der dazu konfiguriert ist, eine Beschleunigung in einem Reifen, welcher an einem Fahrzeug installiert ist, für jeden Punkt in dem Reifen zu messen;
einen Signalanalysator (120), der dazu konfiguriert ist, Signalinformationen von dem Signalempfänger (100) zu empfangen, und eine Profilverschleißrate des Reifens unter Verwendung eines Spitzenwerts einer Beschleunigung in einer Längsrichtung senkrecht zu einer Radialrichtung des Reifens aus Beschleunigungssignalen in dem Reifen zu schätzen;
einen Sender (130), der dazu konfiguriert ist, Analyseinformationen, welche Informationen über die Profilverschleißrate des Reifens sind, von dem Signalanalysator zu empfangen und die Analyseinformationen zu senden; und
ein Steuermodul (200), das dazu konfiguriert ist, die Analyseinformationen von dem Sender (130) zu empfangen und ein Steuersignal für das Fahrzeug, an dem der Reifen installiert ist, zu erzeugen,
wobei der Spitzenwert einer Beschleunigung erhalten wird, wenn der Signalempfänger (110) eine Beschleunigung eines Bodenabschnitts misst, wo der Reifen eine Straßenoberfläche kontaktiert,
wobei die Reifenverschleißmessvorrichtung **dadurch gekennzeichnet ist, dass**

der Signalanalysator (120) dazu konfiguriert ist, den Spitzenwert einer Beschleunigung auf die folgende durch Normalisierung erhaltene Gleichung anzuwenden, was einen Einfluss einer Geschwindigkeit, einer Last und eines Drucks des Reifens ausschließt, um eine Profildicke des Reifens abzuleiten, um eine Profilverschleißrate des Reifens zu schätzen und zu berechnen:

$$f_h(\mathrm{h}) = \frac{Acc_x}{\Omega^2 \theta_r^\alpha}$$

wobei Acc_x ein Spitzenwert einer Beschleunigung ist, h die Profildicke des Reifens ist, Ω eine Winkelgeschwindigkeit des Reifens ist, θ_r ein Kontaktwinkel zwischen dem Reifen und der Straßenoberfläche ist, α ein einzigartiger konstanter Wert für den Reifen ist, f_h(h) eine Funktion ist, die erhalten wird durch Entfernen von Faktoren für die Geschwindigkeit, die Last und den Druck des Reifens von einer Beschleunigungssignalfunktion des Reifens.

2. Die Reifenverschleißmessvorrichtung gemäß Anspruch 1,
wobei Daten über α, was der einzigartige konstante Wert für den Reifen ist, voreingestellt und in dem Signalanalysator gespeichert sind.

3. Die Reifenverschleißmessvorrichtung gemäß Anspruch 1,
wobei das Steuermodul (200) Folgendes aufweist:

eine Fahrzeugsteuerung (210), die dazu konfiguriert ist, das Fahrzeug zu steuern; und
einen Informationssender (220), der dazu konfiguriert ist, die Analyseinformationen von dem Sender zu empfangen und die Analyseinformationen an die Fahrzeugsteuerung zu senden,
wobei die Fahrzeugsteuerung (210) dazu konfiguriert ist, einen Wechselzeitpunkt des Reifens unter Verwendung der Analyseinformationen zu bestimmen.

4. Die Reifenverschleißmessvorrichtung gemäß Anspruch 1,
wobei das Steuermodul (200) ferner eine Anzeige (230) aufweist, die dazu konfiguriert ist, den Wechselzeitpunkt des Reifens oder Informationen über einen Service zum Wechsel des Reifens anzuzeigen.

5. Ein Reifenverschleißmessverfahren unter Verwendung der Reifenverschleißmessvorrichtung gemäß Anspruch 1, das folgende Schritte aufweist:

einen ersten Schritt, bei dem die Beschleunigung in einer Längsrichtung für jeden Punkt in dem Reifen bestimmt wird;
einen zweiten Schritt, in dem eine Profilverschleißrate des Reifens unter Verwendung eines Spitzenwerts der Beschleunigung in der Längsrichtung senkrecht zu der Radialrichtung des Reifens aus Beschleunigungssignalen in dem Reifen geschätzt wird;
einen dritten Schritt, in dem ein Wechselzeitpunkt des Reifens unter Verwendung von Informationen über die Profilverschleißrate des Reifens bestimmt wird; und
einen vierten Schritt, bei dem Informationen über den Wechselzeitpunkt des Reifens an einen Benutzer des Fahrzeugs und ein externes integriertes Steuersystem, das mit dem Fahrzeug verbunden ist, gesendet werden.

Revendications

1. Appareil de mesure d'usure de pneu à l'aide d'une valeur de crête d'accélération d'un pneu, l'appareil comprenant:

un récepteur de signal (100) configuré pour mesurer l'accélération à l'intérieur d'un pneu installé sur un véhicule pour chaque point à l'intérieur du pneu;
un analyseur de signal (120) configuré pour recevoir les informations de signal du récepteur de signal (100) et pour estimer un taux d'usure de la bande de roulement du pneu à l'aide d'une valeur de crête d'accélération dans la direction longitudinale perpendiculaire à une direction radiale du pneu parmi les signaux d'accélération à l'intérieur du pneu;
un émetteur (130) configuré pour recevoir les informations d'analyse, qui sont des informations sur le taux d'usure de la bande de roulement du pneu, à partir de l'analyseur de signal et pour transmettre les informations

d'analyse; et
un module de commande (200) configuré pour recevoir les informations d'analyse de l'émetteur (130) et pour générer un signal de commande pour le véhicule sur lequel est installé le pneu,
dans lequel la valeur de crête d'accélération est acquise lorsque le récepteur de signal (110) mesure l'accélération d'une partie de contact avec le sol où le pneu entre en contact avec une surface de route;
l'appareil de mesure d'usure de pneu étant **caractérisé par le fait que**
l'analyseur de signal (120) est configuré pour appliquer la valeur de crête d'accélération à l'équation suivante obtenue par normalisation, qui exclut l'influence de la vitesse, de la charge et de la pression du pneu, pour dériver une épaisseur de la bande de roulement du pneu pour estimer et calculer un taux d'usure de la bande de roulement du pneu:

$$f_h(h) = \frac{Acc_x}{\Omega^2 \theta_r^{\alpha}}$$

où Acc_x est une valeur de crête d'accélération, h est l'épaisseur de la bande de roulement du pneu, Ω est une vitesse angulaire du pneu, θ est un angle de contact entre le pneu et la surface de route, α est une valeur constante unique pour le pneu, $f_h(h)$ est une fonction obtenue en supprimant les facteurs pour la vitesse, la charge et la pression du pneu d'une fonction de signal d'accélération du pneu.

2. Appareil de mesure d'usure de pneu selon la revendication 1,
dans lequel les données relatives à a, qui est la valeur constante unique pour le pneu, sont préréglées et mémorisées dans l'analyseur de signal.

3. Appareil de mesure d'usure de pneu selon la revendication 1,

dans lequel le module de commande (200) comprend:

un moyen de commande de véhicule (210) configuré pour commander le véhicule; et
un transmetteur d'informations (220) configuré pour recevoir les informations d'analyse de l'émetteur et transmettre les informations d'analyse au moyen de commande de véhicule,

dans lequel le moyen de commande de véhicule (210) est configuré pour déterminer un temps de remplacement du pneu à l'aide des informations d'analyse.

4. Appareil de mesure d'usure de pneu selon la revendication 1,
dans lequel le module de commande (200) comprend par ailleurs un écran d'affichage (230) configuré pour afficher le temps de remplacement du pneu ou les informations relatives à un service de remplacement du pneu.

5. Procédé de mesure d'usure de pneu à l'aide de l'appareil de mesure d'usure de pneu selon la revendication 1, comprenant:

une première étape dans laquelle l'accélération dans une direction longitudinale est déterminée pour chaque point à l'intérieur du pneu;
une deuxième étape dans laquelle un taux d'usure de la bande de roulement du pneu est estimée à l'aide d'une valeur de crête de l'accélération dans la direction longitudinale perpendiculaire à la direction radiale du pneu, parmi les signaux d'accélération à l'intérieur du pneu;
une troisième étape dans laquelle un temps de remplacement du pneu est déterminé à l'aide des informations sur le taux d'usure de la bande de roulement du pneu; et
une quatrième étape dans laquelle les informations relatives au temps de remplacement du pneu sont transmises à un utilisateur du véhicule et à un système de commande intégré externe connecté au véhicule.

FIG. 1

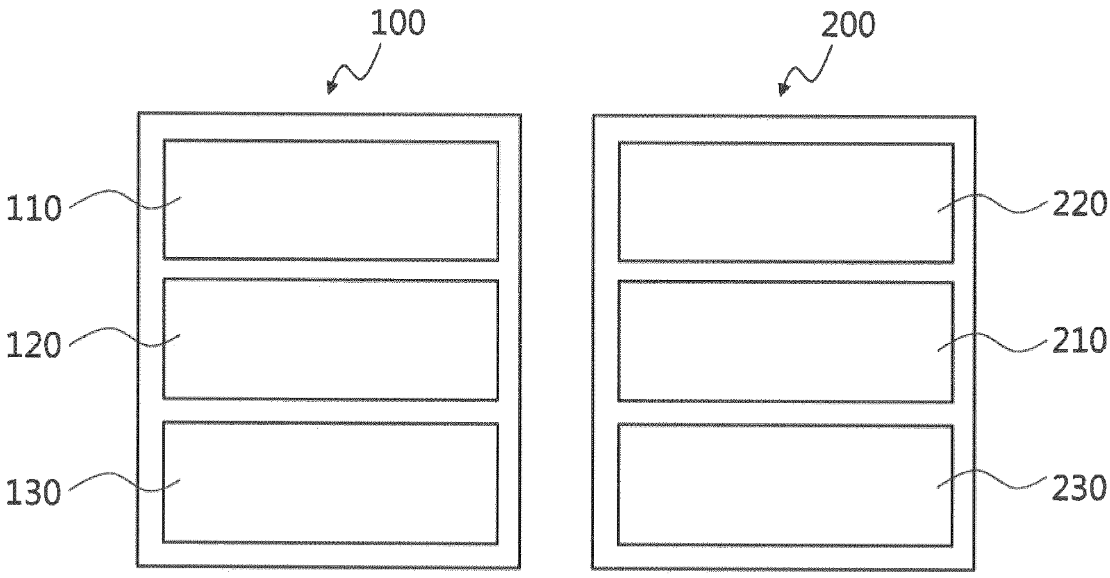


FIG. 2

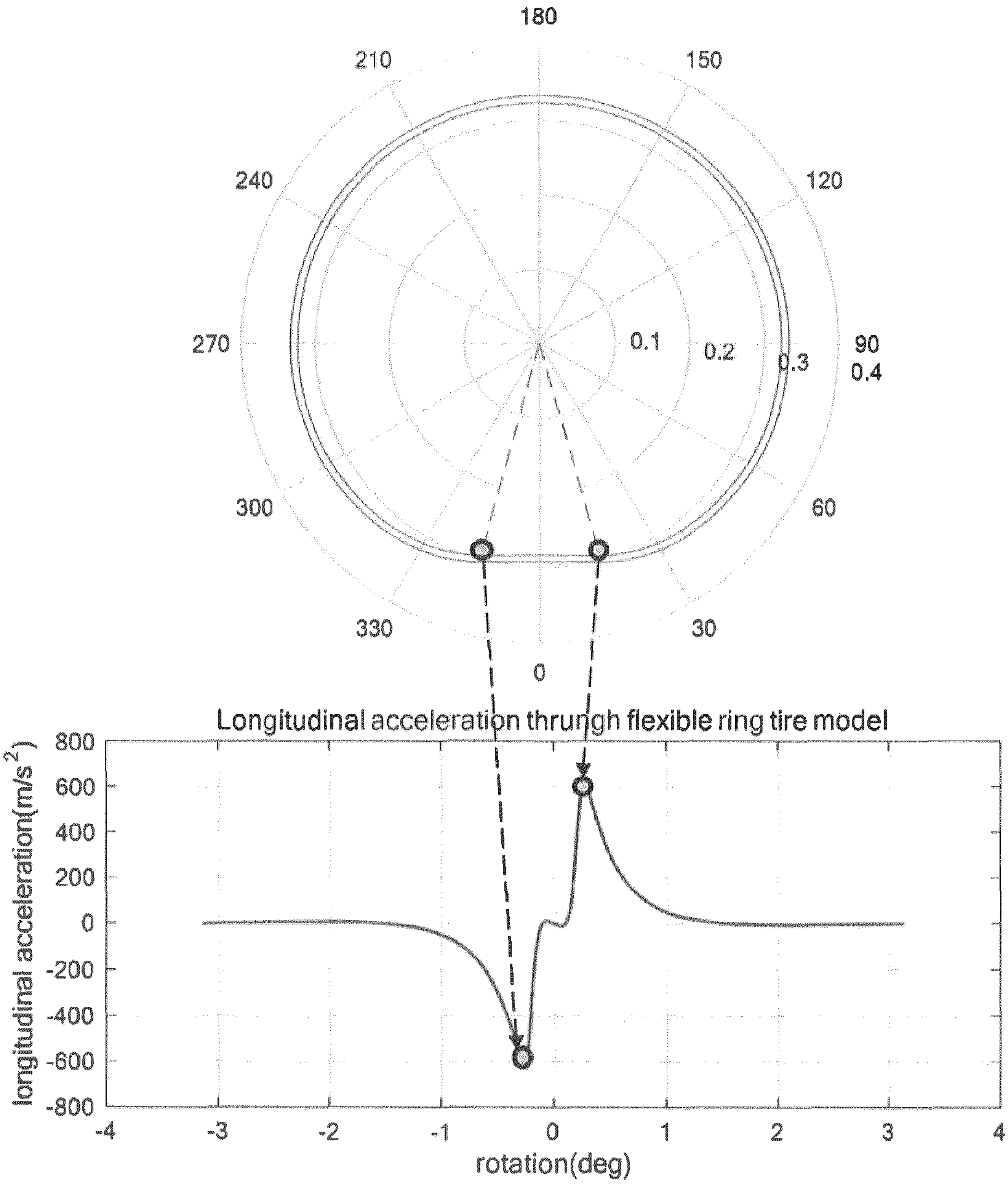

180
210
150
240
120
270
0.1
0.2
0.3
90
0.4
300
60
330
30
0
Longitudinal acceleration thrurgh flexible ring tire model
longitudinal acceleration(m/s2)
800
600
400
200
0
-200
-400
-600
-800
-4
-3
-2
-1
0
1
2
3
4
rotation(deg)

FIG. 3

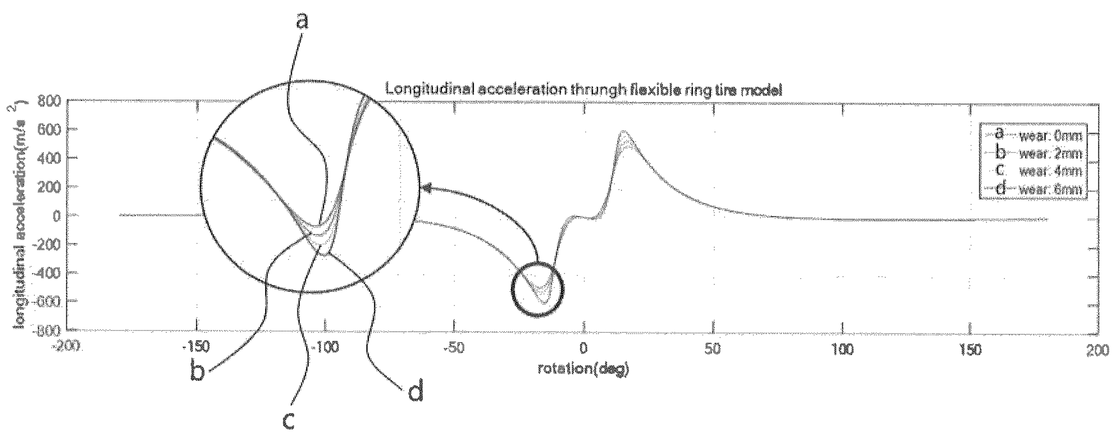

Longitudinal acceleration thrungh flexible ring tire model
longitudinal acceleration(m/s^2)
rotation(deg)
a wear: 0mm
b wear: 2mm
c wear: 4mm
d wear: 6mm
a
b
c
d

FIG. 4

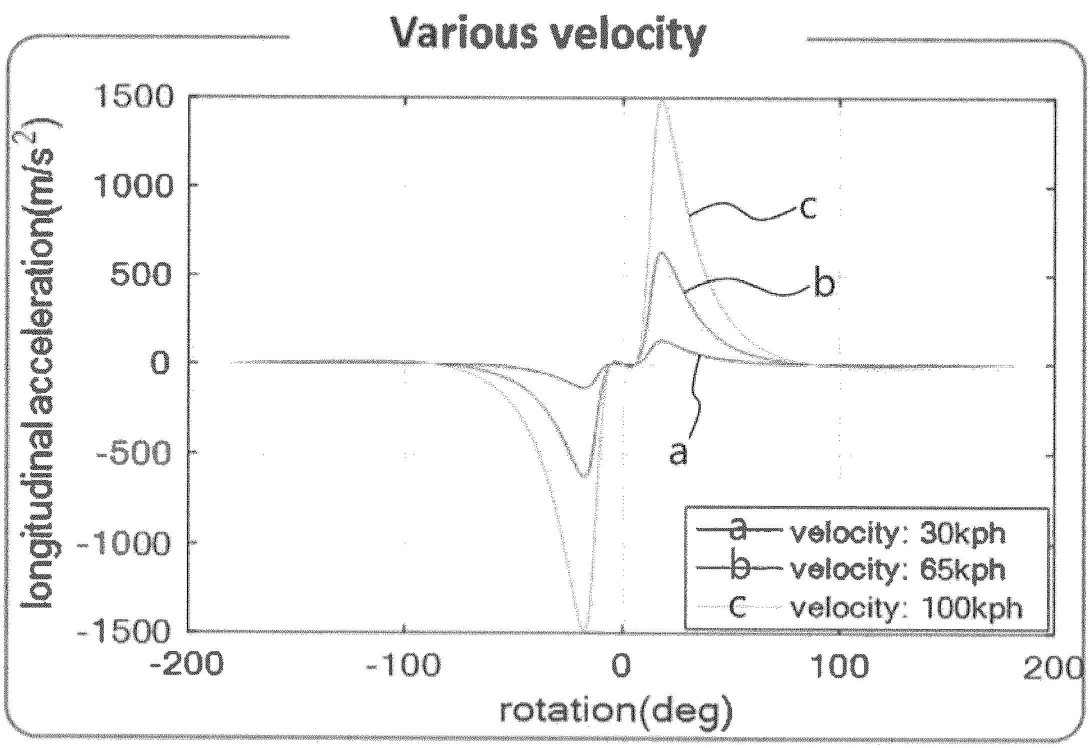

Various velocity
longitudinal acceleration(m/s^2)
rotation(deg)
a velocity: 30kph
b velocity: 65kph
c velocity: 100kph
a
b
c

FIG. 5

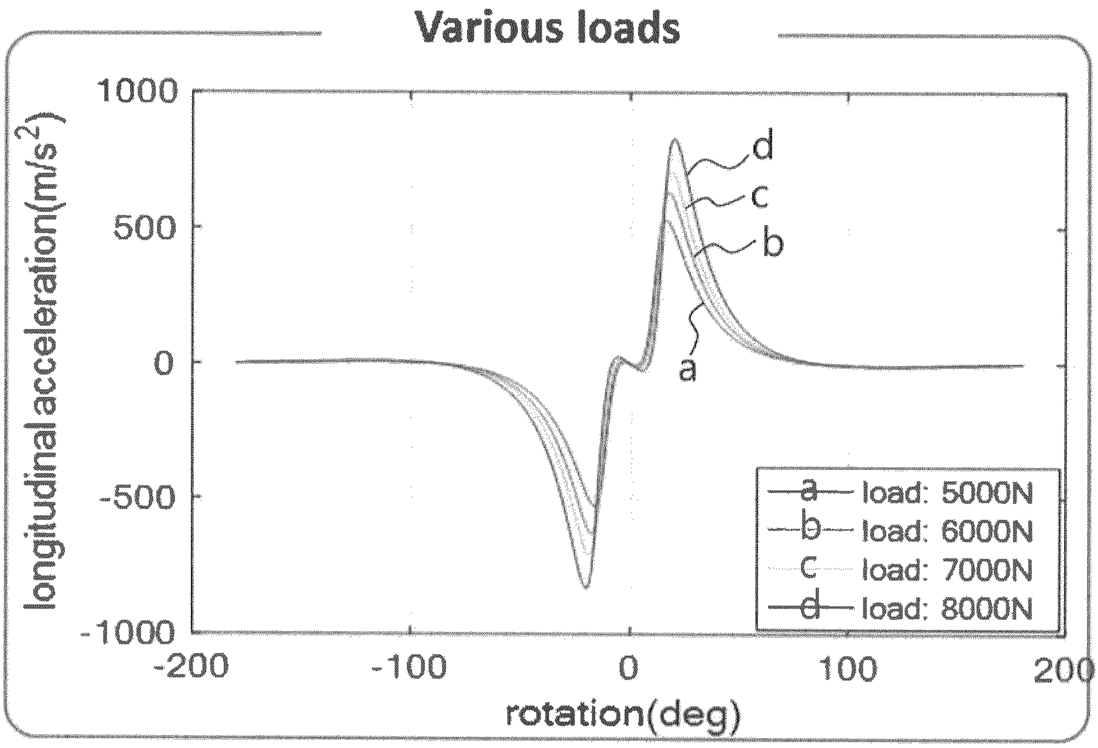

Various loads
1000
500
0
-500
-1000
longitudinal acceleration(m/s^2)
-200
-100
0
100
200
rotation(deg)
a
b
c
d
a load: 5000N
b load: 6000N
c load: 7000N
d load: 8000N

FIG. 6

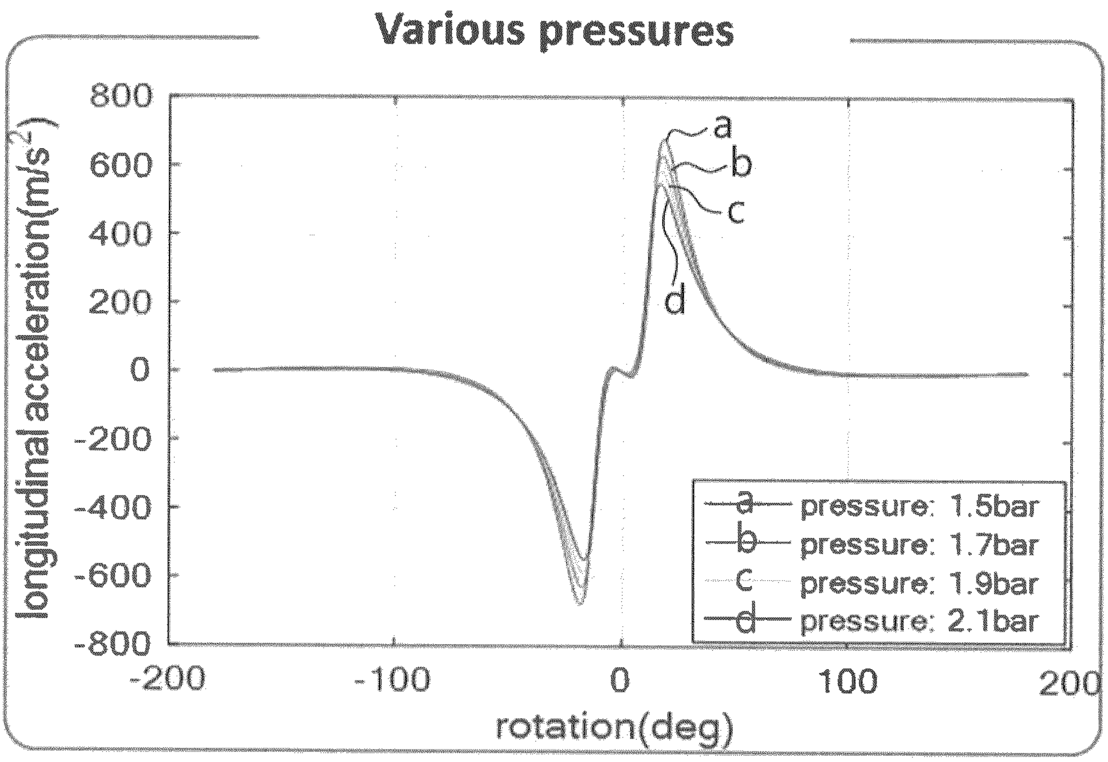

Various pressures
800
600
400
200
0
-200
-400
-600
-800
longitudinal acceleration(m/s^2)
-200
-100
0
100
200
rotation(deg)
a
b
c
d
a pressure: 1.5bar
b pressure: 1.7bar
c pressure: 1.9bar
d pressure: 2.1bar

FIG. 7

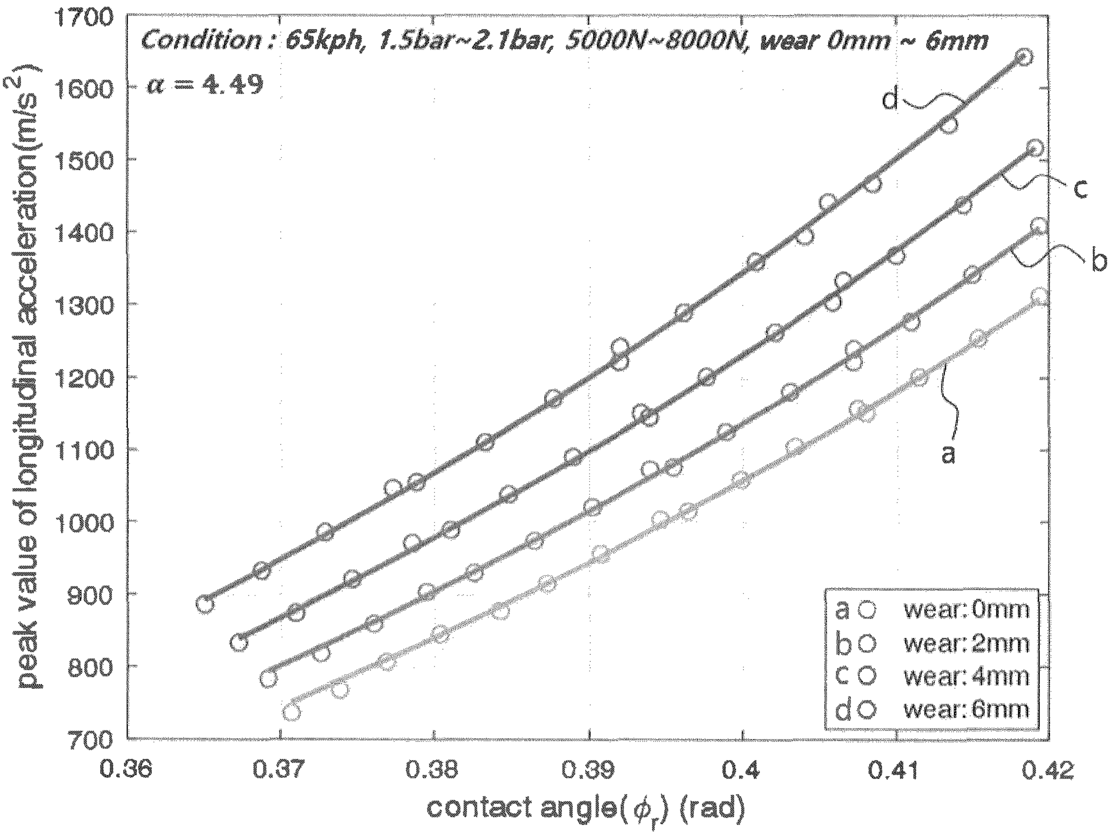

Condition : 65kph, 1.5bar~2.1bar, 5000N~8000N, wear 0mm ~ 6mm
$\alpha = 4.49$
peak value of longitudinal acceleration(m/s^2)
contact angle(ϕ_r) (rad)
a wear: 0mm
b wear: 2mm
c wear: 4mm
d wear: 6mm
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
0.36
0.37
0.38
0.39
0.4
0.41
0.42

FIG. 8

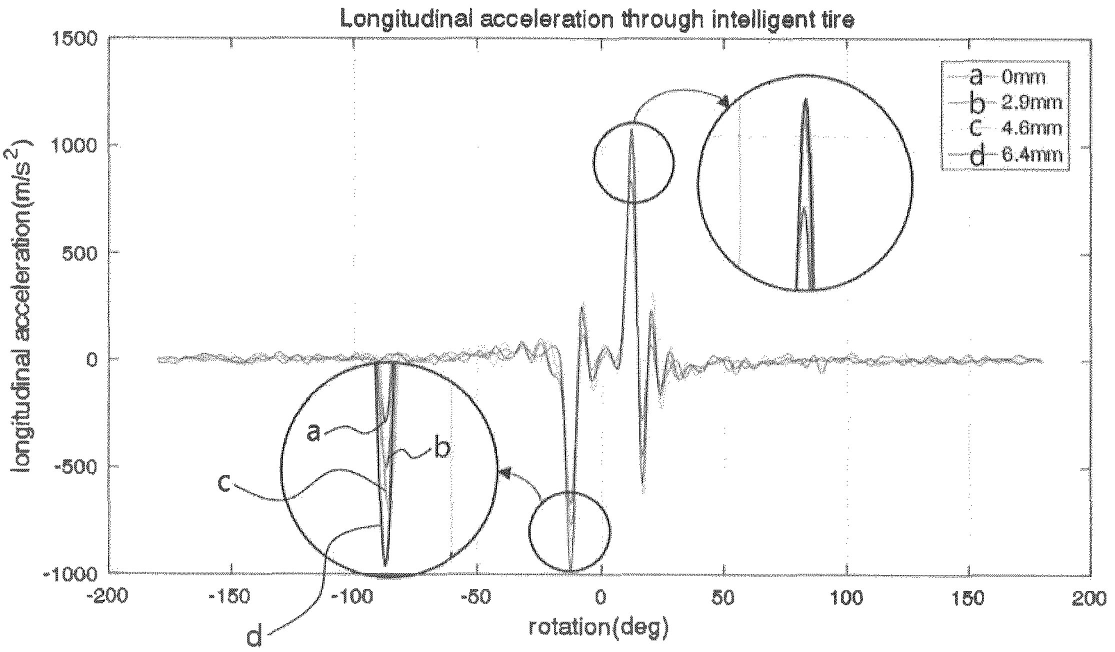
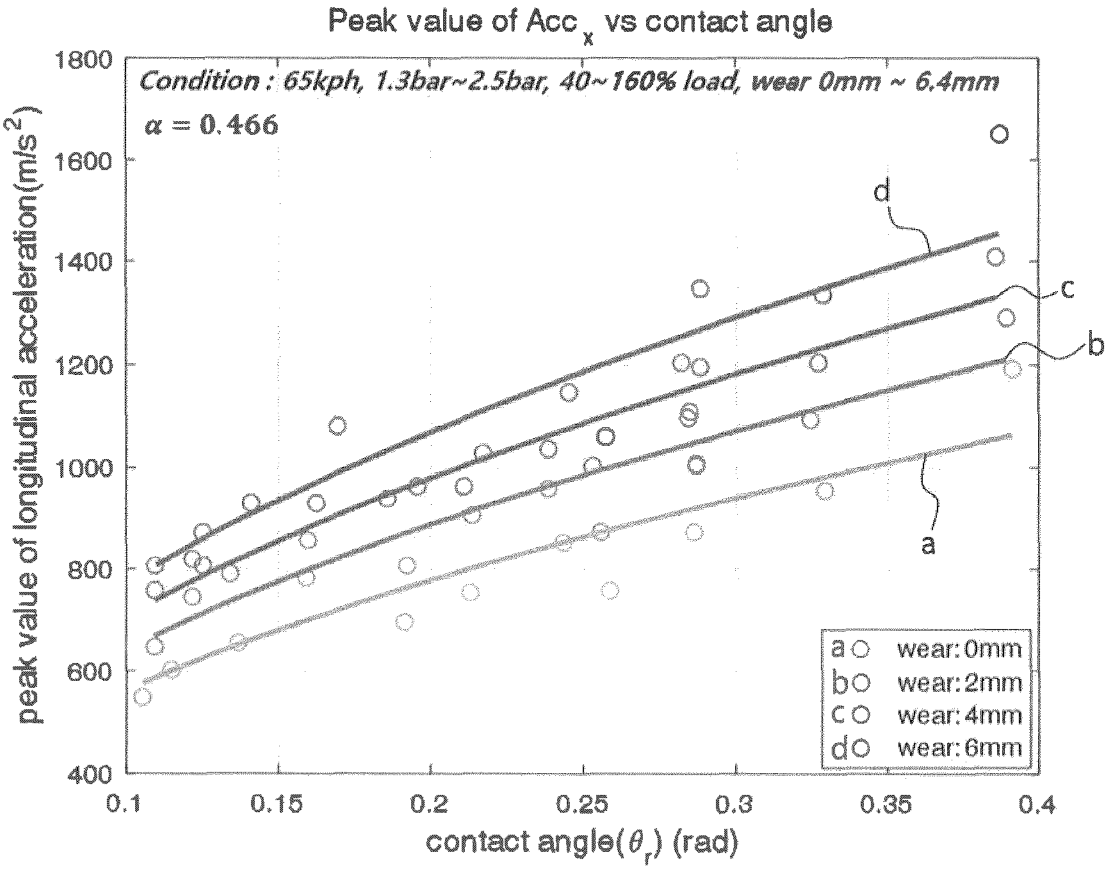

Longitudinal acceleration through intelligent tire
longitudinal acceleration(m/s^2)
rotation(deg)
a 0mm
b 2.9mm
c 4.6mm
d 6.4mm
1500
1000
500
0
-500
-1000
-200
-150
-100
-50
0
50
100
150
200

FIG. 9



Peak value of Acc x vs contact angle
Condition : 65kph, 1.3bar~2.5bar, 40~160% load, wear 0mm ~ 6.4mm
α = 0.466
peak value of longitudinal acceleration(m/s²)
contact angle(θr) (rad)
1800
1600
1400
1200
1000
800
600
400
0.1
0.15
0.2
0.25
0.3
0.35
0.4
a
b
c
d
a wear: 0mm
b wear: 2mm
c wear: 4mm
d wear: 6mm

FIG. 10

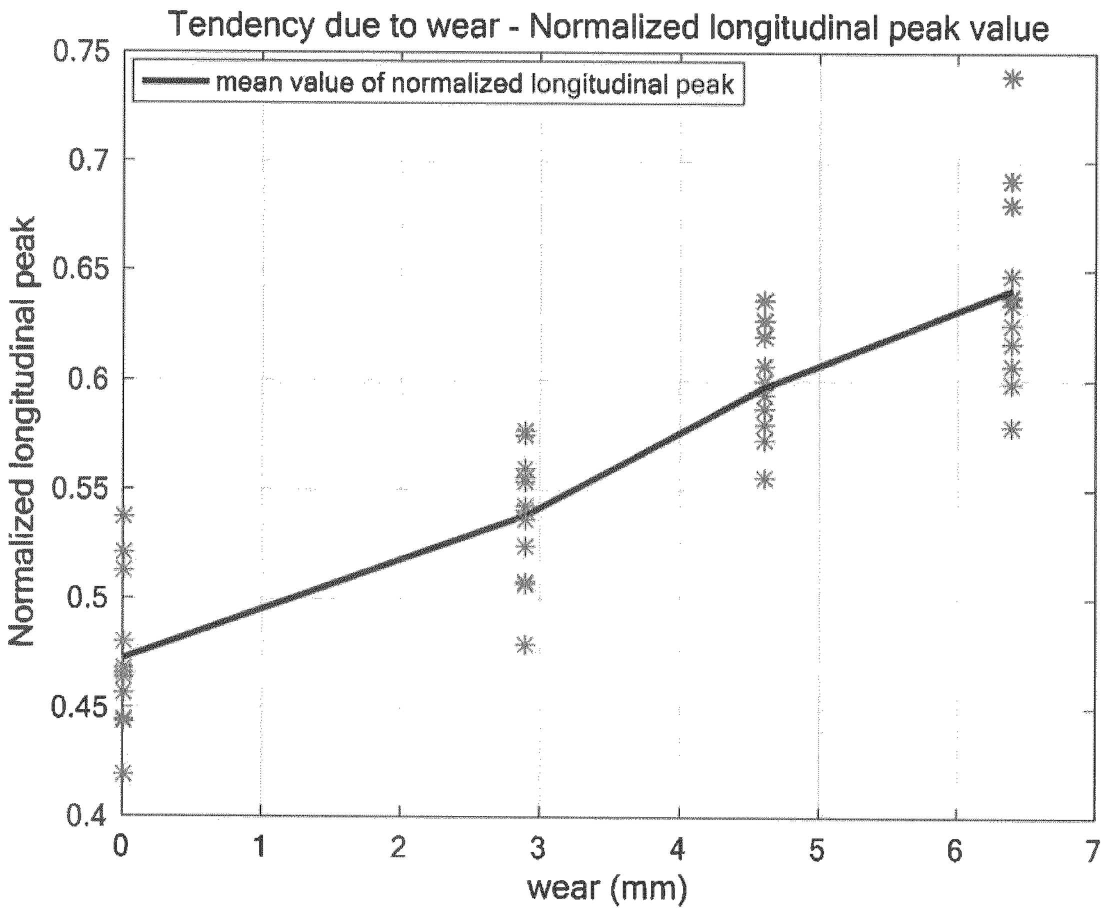
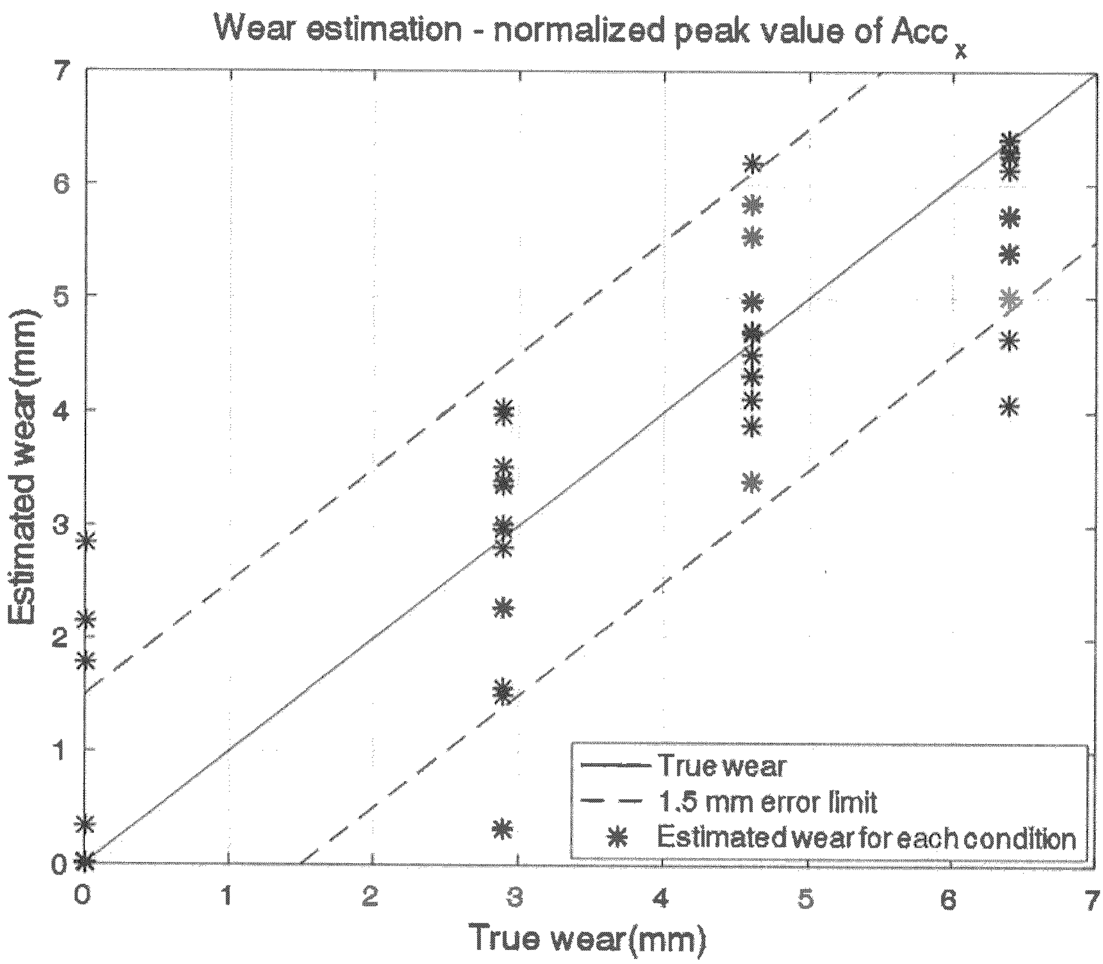

Tendency due to wear - Normalized longitudinal peak value
mean value of normalized longitudinal peak
Normalized longitudinal peak
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0
1
2
3
4
5
6
7
wear (mm)

FIG. 11



Wear estimation - normalized peak value of Acc x
Estimated wear(mm)
True wear(mm)
0
1
2
3
4
5
6
7
True wear
1.5 mm error limit
Estimated wear for each condition

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 20170113495 **[0004] [0005]**
- US 8483976 B **[0004] [0005]**
- US 8061191 B **[0004] [0005]**