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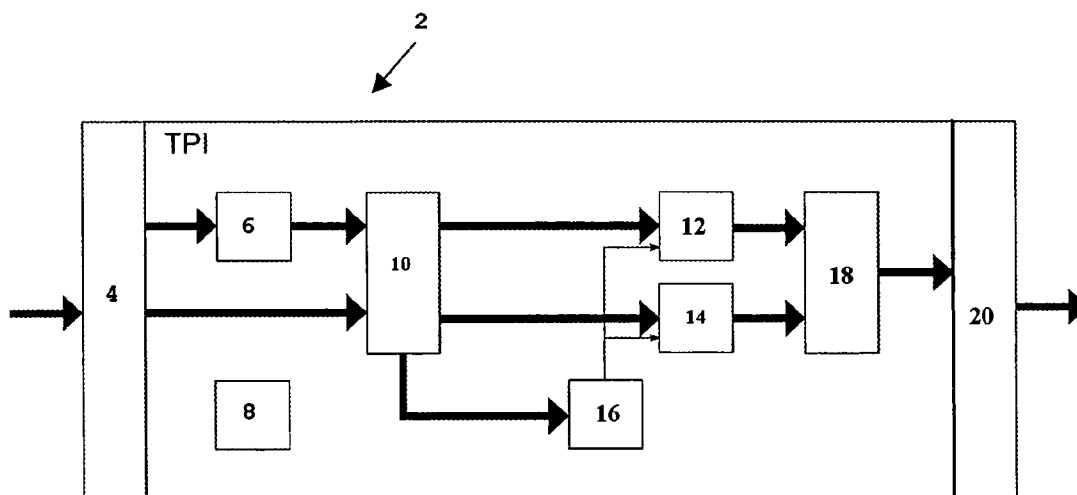


Fig. 1

(57) Abstract: In indirect tire pressure monitoring of tires of a vehicle, the following steps and means to carry out the same, respectively, are contemplated: - providing a tire classification database indicating at least one classified tire type; - determining a vehicle tire type for the vehicle on the basis of vehicle data in including information on at least one tire currently used with the vehicle,- - determining whether the vehicle tire type can be associated to one of the at least one classified tire type; and - , in the case an association is determined, monitoring tire pressure according to the associated classified tire type.

WO 2008/113378 A1

**TIRE PRESSURE CLASSIFICATION
BASED TIRE PRESSURE MONITORING**

Field of the invention

The present invention relates to indirect tire pressure
5 monitoring of tires of a vehicle on the basis of tire
classification information.

Background of the invention

Monitoring of tire pressure can be assumed to become a
standard functionality in vehicles, at least in cars and
10 trucks, not only due to governmental and legal regulations but
also in view of a general demand for enhanced vehicle safety.

The importance of having correct tire inflation pressure is
well known. The inflation pressure directly affects, e.g., the
vehicle handling, the load capacity, and the fuel consumption.
15 There are studies that indicate that tire related problems are
the third most common reason for breakdown of passenger
vehicles. Furthermore, it has been shown that a majority of
all tire flat-outs is preceded by under-inflation or slow air
leakage. With tire pressure monitoring that detects the
20 presence of air leakages, severe accidents can thus be
avoided.

Besides these well known facts about the importance of having
a correct inflation pressure, tire pressure monitoring has
become even more important since legal regulations in some
25 countries require all new motor vehicles to be equipped with a
system that monitors the tire pressure.

There are two alternative approaches to monitor the tire
pressure. One way is to mount a pressure sensor inside the
tire and transfer the pressure sensor value wireless to an on-

board tire pressure system of the vehicle. This approach is referred to as "direct tire pressure monitoring". The other alternative, called "indirect tire pressure monitoring", uses existing sensors (e.g. control and/or detection devices of vehicles, ECUs (electronic control unit), antilock braking systems, dynamic stability systems, anti-spin systems and traction control systems, in form of digital and/or analog data and/or signals) to compute quantities related to the tire pressure. Indirect tire pressure monitoring is not directly measuring the air/gas pressure in a tire. Rather, parameters correlated with tire pressure are calculated using data available from the vehicle (e.g. from brake system or the electronic stability control system) and, on the basis of such parameters, tire pressure is indicated.

Vehicle data commonly used in tire pressure monitoring is data indicating an effective roll radius of wheel/tire. For the sake of illustration, it will be referred to such wheel radius data in the following.

However, there are several effects possibly influencing actual tire pressure and, thus, relation(s) between actual tire pressure and data from which actual tire pressure, an estimation thereof or tire pressure deviation is to be derived.

For example, current driving situations (e.g. acceleration, deceleration; driving on smooth road surfaces vs. rough road surfaces; driving in curves etc.), temperature(s) affecting tire pressure and the like may influence actual tire pressure and should be therefore take into account in indirect tire pressure monitoring.

Further, different tire types will have different properties that may be also taken into account in indirect tire pressure monitoring. For example, different tires (brand, dimension,

winter/summer, etc.) to some extent respond differently to changes in inflation pressure, e.g., for a given amount of tire pressure loss, a corresponding change in e.g. effective roll radius will differ between different tires. To ensure a reliable indirect tire pressure monitoring a consistent behavior in general, it would be helpful to specify the behavior of the pressure related parameters of tire(s).

To this end, an approach may be performing in-vehicle tests where a vehicle equipped with a tire type of interest is actually driven, wherein, e.g., pressure related tire behavior may be specified. However, such an approach will be time-consuming and expensive.

Object of the invention

The object of present invention is to improve indirect tire pressure monitoring such that tire related effects may be taken into account in a more easy and technically and economically feasible manner.

Summary of the invention

To solve the above object, the present invention provides a method, a system and a computer program product as defined in the independent claims.

According to a first aspect the present invention provides method of indirect tire pressure monitoring of tires of a vehicle, which method comprises the steps of:

- providing a tire classification database indicating at least one classified tire type;
- determining a vehicle tire type for the vehicle on the basis of vehicle data including information on at least one tire currently used with the vehicle;
- determining whether the vehicle tire type can be associated

to one of the at least one classified tire type; and
- , in the case an association is determined, monitoring tire pressure according to the associated classified tire type.

According to another aspect, the present invention provides a
5 system for indirect tire pressure monitoring of tires of a vehicle, comprising:

- a tire classification database indicating at least one classified tire type;

- a vehicle tire type determination unit being adapted to
10 determine a vehicle tire type for the vehicle on the basis of vehicle data in including information on at least one tire currently used with the vehicle;

- an association determination unit being adapted to determine whether the vehicle tire type can be associated to one of the
15 at least one classified tire type; and

- a tire pressure monitoring unit being adapted to, in the case an association is determined, monitor tire pressure according to the associated classified tire type.

In a still further aspect, the present invention provides
20 computer program product, the computer program product comprising program code for carrying out, when executed on a processing system, the steps of:

- providing a tire classification database indicating at least one classified tire type;

- determining a vehicle tire type for the vehicle on the basis
25 of vehicle data in including information on at least one tire currently used with the vehicle;

- determining whether the vehicle tire type can be associated to one of the at least one classified tire type; and

- , in the case an association is determined, monitoring tire
30 pressure according to the associated classified tire type.

Further aspects, features and advantages of the present invention will become apparent from the below description, the accompanying drawings and the appended claims.

Short description of the drawings

Embodiments of the invention will now be described, by way of example and with reference to the accompanying drawings, in which:

- 5 Fig. 1 schematically illustrates an indirect tire pressure monitoring system according to an embodiment of the present invention;
- Fig. 2 schematically illustrates forces considered in tire classification according to the present invention; and
- 10 Fig. 3 shows graphs schematically illustrating wheel speed spectrum data and tire force spectrum data.

Description of preferred embodiments

Fig. 1 schematically illustrates a system according to the present invention, particularly in form of a tire pressure
15 deviation (TPD) warning system 2 using indirect tire pressure monitoring.

The present invention is provided for use in any kind of vehicle having at least one wheel equipped with at least one tire. The term "vehicle" as used herein comprises any type of
20 vehicle, such as cars, bikes, trucks, trailers, and the like, where information on the basis of which indirect tire pressure monitoring is possible.

A "pressure deviation" in a tire may be detected if the tire pressure actually determined for the tire differs from a
25 normal/predefined/desired tire pressure and/or differs from the pressure of one or more other tires by a predetermined threshold value.

As used herein, "on the basis of ... " and "based on ... " indicate that at least the "... " is used as basis and should not be construed to be limited to the "...", for example, "on the basis of the at least one vehicle data" indicates that at least the at least one vehicle data are used and that further, e.g., data and/or information may be used.

Further, the present invention may use vehicle data on the basis of which tire pressure monitoring is possible.

Contemplated vehicle data include at least one of:

- 10 - vehicle data indicative of ambient temperature;
- vehicle data indicative of a temperature of an engine of the vehicle;
- vehicle data indicative of an engine torque of an engine of the vehicle;
- 15 - vehicle data indicative of a torque acting on the at least one tire;
- vehicle data indicative of a engine speed of an engine of the vehicle;
- vehicle data indicative of a yaw rate of the vehicle;
- 20 - vehicle data indicative of a speed of the vehicle;
- vehicle data indicative of at least one of a lateral acceleration and a longitudinal acceleration of the vehicle;
- vehicle data indicative of a steering wheel angle of a steering wheel of the vehicle;
- 25 - vehicle data indicative of a driving condition of the vehicle, particularly a braking condition;
- vehicle data indicative that a gear shift of the vehicle is in progress;
- vehicle data indicative that a braking system of the vehicle
- 30 is operating;
- vehicle data indicative of brake pressure; and
- vehicle data indicative that at least one active control device of the vehicle is active.

However, before continuing with descriptions of the drawings, some further observations to further aspects of the present invention are given. More detailed observation to the method related aspects of the present invention also apply to
5 corresponding system related aspects and computer program related aspects of the present invention even if not explicitly noted.

In the method of the present invention, the tire classification database may indicate, in association to each
10 of the at least one classified tire type, at least one of at least one parameter setting for tire pressure monitoring and at least one operation mode for tire pressure monitoring; wherein the method of the present invention may further comprise a step of retrieving at least one of the at least one
15 parameter setting and at least one operation mode from the tire classification database, wherein the step of tire pressure monitoring is performed according to the retrieved at least one parameter setting and operation mode.

For example, if a tire has been classified (e.g. by precise
20 parameters or at least a rough assignment to a respective group/type of tires), classification information may be used for, e.g., controlling/selecting a size of calibration slots in roll radius based indirect tire pressure monitoring (e.g. using wheel/tire radius analysis) and/or wheel/tire spectrum
25 analysis, how much data should be used in each slot, adaptation speeds in roll radius based indirect tire pressure monitoring (e.g. using wheel/tire radius analysis) and/or wheel/tire spectrum analysis, indicators, warning thresholds, timers, sensitivity levels etc.

30 In the method of the present invention the step of determining the vehicle tire type may include a step of determining an overall vehicle tire type for the vehicle.

An overall vehicle tire type may indicate a tire type common to all vehicle tires or may be a "virtual" tire type (e.g. based on computations of information on vehicle tires of the same type) having properties, characteristics and,
5 particularly, pressure related behavior at least partially suitable and/or acceptable for all vehicle tires irrespective of their actual types.

In such embodiments, the step of tire pressure monitoring may be performed for at least two different tires of the vehicle
10 according to the associated classified tire type. For example, a single associated classified tire type may be used as basis for tire pressure monitoring for all vehicle tires.

In the method of the present invention, the step of determining the vehicle tire type may be performed to
15 determine an individual vehicle tire type for at least two different tires of the vehicle.

An individual vehicle tire type may be the actual tire type of a tire being of interest (e.g. to be tire pressure monitored).

In such embodiments, the step of determining whether the
20 vehicle tire type can be associated to one of the at least one classified tire type may be performed with respect to each of the at least two different tires.

Further, the step of tire pressure monitoring may be performed for each of the at least two different tires according to the
25 respectively associated classified tire type. For example, for each vehicle tire type, an associated classified tire type may be used as basis for tire pressure monitoring for all vehicle tires, i.e. more than one associated classified tire types may be used.

In the method of the present invention, the step of determining the vehicle tire type may include a step of determining at least one characteristic of a tire of the vehicle; and the step of determining whether the vehicle tire
5 type can be associated to one of the at least one classified tire type may include a step of determining whether one of the at least one classified tire type have at least one characteristic being at least comparable with the determined at least one vehicle tire characteristic.

10 In the method of the present invention, the step of determining the vehicle tire type may include a step of wheel speed spectrum analysis to obtain a wheel speed spectrum data for the at least one tire.

In such embodiments, the step of determining whether the
15 vehicle tire type can be associated to one of the at least one classified tire type may include a step of determining whether the tire classification database includes data indicating a tire type having tire force spectrum data being at least comparable with the wheel speed spectrum data.

20 In the method of the present invention, the step of wheel speed spectrum analysis may include a step of determining wheel speed resonance center of gravity data for the at least one tire.

In such embodiments, the step of determining whether the
25 vehicle tire type can be associated to one of the at least one classified tire type may include a step of determining whether the tire classification database includes data indicating a tire type having a tire force resonance center of gravity data being at least comparable with the wheel speed resonance
30 center of gravity data.

In the method of the present invention, the step of wheel spectrum analysis may include a step of determining wheel speed resonance width data for the at least one tire.

5 Here, step of determining whether the vehicle tire type can be associated to one of the at least one classified tire type may include a step of determining whether the tire classification database includes data indicating a tire type having a tire force resonance width data being at least comparable with the wheel speed resonance width data.

10 The method of the present invention may further include a step of generating the tire classification database on the basis of testing at least one to be classified tire in a test environment.

15 In such embodiments, the step of generating the tire classification database may include a step of determining, for the at least one to be classified tire, data indicating characteristic tire oscillations.

20 According to the method of the present invention, the step of generating the tire classification database may include a step of determining, for the at least one to be classified tire, data indicating tire oscillations in tangential tire direction.

25 Further in the method of the present invention, the step of generating the tire classification database may include a step of determining, for the at least one to be classified tire, data indicating tire oscillations in radial tire direction.

30 In the method of the present invention, the step of generating the tire classification database may include a step of determining, for the at least one to be classified tire, tire force spectrum data.

In the method of the present invention, the step of generating the tire classification database may include a step of determining, for the at least one to be classified tire, tire force resonance center of gravity data.

- 5 In the method of the present invention, the step of generating the tire classification database may include a step of determining, for the at least one to be classified tire, tire force resonance width data.

In the method of the present invention, the step of
10 determining tire force spectrum data may be based on the data indicating tire oscillations in tangential tire direction; and/or the step of determining tire force resonance center of gravity data may be based on the data indicating tire
oscillations in tangential tire direction; and/or the step of
15 determining tire force resonance width data may be based on the data indicating tire oscillations in tangential tire direction.

In the method of the present invention, the step of
determining tire force spectrum data may be based on the data
20 indicating tire oscillations in radial tire direction; and/or the step of determining tire force resonance center of gravity data may be based on the data indicating tire oscillations in radial tire direction; and the step of determining tire force
resonance width data may be based on the data indicating tire
25 oscillations in radial tire direction.

In the method of the present invention, the step of generating the tire classification database may include a step of determining, for the at least one to be classified tire, at least one of at least one parameter setting for indirect tire
30 pressure monitoring and at least one operation mode for indirect tire pressure monitoring.

In the method of the present invention, in the case the step of determining whether the vehicle tire type can be associated to one of the at least one classified tire type fails, the step of tire pressure monitoring may be performed on the basis of at least one of a default parameter setting and a default operation mode.

In the system of the present invention, the tire classification database may indicate, in association to each of the at least one classified tire type, at least one of at least one parameter setting for tire pressure monitoring and at least one operation mode for tire pressure monitoring; wherein the system of the present invention may further comprise a retrieving unit being adapted to retrieve at least one of the at least one parameter setting and at least one operation mode from the tire classification database, wherein the tire pressure monitoring unit may be adapted to perform tire pressure monitoring according to the retrieved at least one parameter setting and operation mode.

In the system of the present invention, the vehicle tire type determination unit may be adapted to determine an overall vehicle tire type for the vehicle.

Here, the tire pressure monitoring unit may be adapted to perform tire pressure monitoring for at least two different tires of the vehicle according to the associated classified tire type.

In the system of the present invention, the vehicle tire type determination unit may be adapted to determine an individual vehicle tire type for at least two different tires of the vehicle.

In such embodiments, the association determination unit may be adapted to determine whether the vehicle tire type can be

associated to one of the at least one classified tire type with respect to each of the at least two different tires.

Further, the tire pressure monitoring unit may be adapted to perform tire pressure monitoring for each of the at least two
5 different tires according to the respectively associated classified tire type.

In the system of the present invention, the vehicle tire type determination unit may be adapted to determine at least one characteristic of a tire of the vehicle; and the association
10 determination unit may be adapted to determine whether one of the at least one classified tire type has at least one characteristic being at least comparable with the determined at least one vehicle tire characteristic.

In the system of the present invention, the vehicle tire type
15 determination unit may be adapted to perform wheel speed spectrum analysis to obtain a wheel speed spectrum data for the at least one tire.

Here, the association determination unit may be adapted to determine whether the tire classification database includes
20 data indicating a tire type having tire force spectrum data being at least comparable with the wheel speed spectrum data.

According to the present invention, the association determination unit may be adapted to determine wheel speed resonance center of gravity data for the at least one tire.

25 Then, the vehicle tire type determination unit may be adapted to determine whether the tire classification database includes data indicating a tire type having a tire force resonance center of gravity data being at least comparable with the wheel speed resonance center of gravity data.

In the system of the present invention, the association determination unit may be adapted to determining wheel speed resonance width data for the at least one tire.

5 In such embodiments, the vehicle tire type determination unit may be adapted to determine whether the tire classification database includes data indicating a tire type having a tire force resonance width data being at least comparable with the wheel speed resonance width data.

10 The system of the present invention may further include means being adapted to carry out the steps set forth above with respect to generation of the tire classification database.

15 Further, in the system of the present invention, in the case the vehicle tire type can be associated to one of the at least one classified tire type fails, the tire pressure monitoring unit may be adapted to perform tire pressure monitoring on the basis of at least one of a default parameter setting and a default operation mode.

20 The computer program product of the present invention may further comprise program code for carrying out, when executed on a processing system, the steps of at least one of the above-mentioned possible embodiments of the method of the present invention.

25 The computer program product of the present invention may be stored on a computer-readable storage medium or in a computer-readable storage device.

Now, referring to the drawings again, Fig. 1 schematically illustrates a principle system arrangement according to the present invention, particularly in form an tire pressure deviation (TPD) warning system 2.

The TPD warning system 2 may for example be a hardware and/or software component, which is integrated in an electronic control unit (e.g. ECU) of a vehicle. The system 2 obtains so-called vehicle data by means of an interface unit 4, which may
5 be - in the case of an at least partially software based implementation - an application program interface (API). The vehicle data may include vehicle signals from the vehicle CAN bus e.g. describing the vehicle condition. The vehicle data may (further) include measuring data, information, signals and
10 the like directly obtained and/or indirectly derived from vehicle's sensors, such as rotational speed sensors (as existent in the vehicle's ABS), which indicate angular velocities of rotating wheels and tires, respectively.

In particular, the vehicle data may be indicative of ambient
15 temperature, temperature of an engine of the vehicle, wheel/tire angular velocity, wheel/tire rotational speed, engine torque of an engine of the vehicle, torque acting on the at least one tire, engine speed of an engine of the vehicle, yaw rate of the vehicle, speed of the vehicle,
20 lateral and/or longitudinal acceleration of the vehicle, steering wheel angle of a steering wheel of the vehicle, of a driving condition of the vehicle, particularly a braking condition, gear shift of the vehicle being in progress and an active control device of the vehicle being actively operating.

25 Any of such data may be used by units for determining tire pressure indicating data, which units are described below. However, in embodiments described here, particularly, wheel/tire angular velocity and/or wheel/tire rotational speed may be used for tire pressure determination and can be
30 considered as an example for information indirectly indicating tire pressure.

To provide such vehicle data, an ECU and/or sensors of the vehicle may be used. For example, temperature sensor(s), yaw

rate sensor(s), torque sensor(s), speed sensor(s), accelerator sensor(s), and/or sensors indicating accelerator pedal, clutch pedal and/or braking pedal position(s) may be employed to acquire vehicle data and/or to perform measurements on the basis of which vehicle data may be derived.

The vehicle data may directly provided to units of system 2 and/or may be stored in a memory unit 6 for later use.

A diagnosis control unit 8 performs internal system and input signal checks and sets system status and error codes, which may be considered as device status data and/or error indicating data. If a severe error occurs, this unit can disable the system 2.

Obtained vehicle data may be input to a preprocessing unit 10, which may process (e.g. filters) vehicle data, for example, to remove disturbances and offsets, and may pre-compute vehicle data such that they can be used by other system parts.

Signals output by preprocessing unit 10 are input to a unit for roll radius based indirect tire pressure monitoring, here exemplarily in form of a wheel radius analysis (WRA) unit 12, and/or a wheel spectrum analysis (WSA) unit 14. To WRA unit 12 and a WSA unit 14 will be provided vehicle data (unprocessed and/or processed by preprocessing unit 10) at least indicating wheel/tire angular velocity and/or wheel/tire rotational speed. Further vehicle signals may be related to wheel/tire angular velocity "energy", yaw rate, yaw rate from wheel/tire velocity, engine torque, braking in progress, reverse driving in progress, active control in progress, vehicle speed, longitudinal acceleration, lateral acceleration, wheel slip, normalized traction force, gear shift in progress, data quality indicators (dynamic driving, slip variance, etc.), ambient temperature and vehicle status.

In some embodiments, WRA unit 12 and WSA unit 14 may be further provided data indicating, e.g., special driving conditions (e.g. driving with snow chains, on rough roads, on oval track and in a roundabout etc.). Such data may be generated by a dynamic state detector unit 16 based on vehicle data from interface 4, memory 6 and/or preprocessing unit 10. Thus, data from dynamic state detector unit 16 may be also referred to as vehicle data as they are derived there from and can be considered as driving situation/scenario indicating data according to some embodiments of the present invention.

Wheel radius analysis as executed in the WRA unit 12 are based on the fact that the wheel speed of a wheel depends on the respective wheel radius: the wheel speed increases with decreasing wheel radius. Changes in the wheel radius contain information about changes in the tire pressure of the corresponding wheels, but may also reflect, e.g., vehicle load changes and surface changes or react on driving forces (acceleration, braking, forces in curves etc.).

WRA unit 12 may detect relative changes in tire pressure with respect to at least two tires.

Based on the wheel angular velocity signals, WSA unit 14 detects changes in the spectral properties of each of the four wheel angular velocity signals. The tire pressure has significant influence on the characteristics of the spectrum of the angular velocity signal; however, further conditions (e.g. driving situation, road surface and temperature) may also have an impact on the angular velocity signal spectrum and may be therefore considered.

WSA unit 14 may detect changes in tire pressure for each wheel individually, for example by calculating a parametric model of the wheel/tire velocity spectrum and using the parameters of this model to calculate a spectral shape factor that condenses

the different pressure dependent features of the spectrum into one single scalar quantity.

In further embodiments, WSA unit 14 may use DFT-based approach(es) or method(s) to determine wheel/tire spectrum.

5 According to embodiments described here, WSA unit 14 may be considered as implementation of the step of determining the vehicle tire type and/or the vehicle tire type determination unit or at least a part of such an implementation; in the latter case below described combination unit 18 may be
10 considered as implementation of remaining parts.

In addition or as alternative, WSA unit 14 may be considered as implementation of the step of tire pressure monitoring and/or the tire pressure monitoring unit or at least a part of such an implementation; in the latter case below described
15 combination unit 18 may be considered as implementation of remaining parts.

Tire pressure indicating data may provided by WRA unit 12 only or by WSA unit 14 only or by both WRA unit 12 and WSA unit 14.

A combination unit 18 obtains data from WRA unit 12 and/or WSA
20 unit 14 and from interface unit 4, memory unit 6 and/or preprocessing unit 10. According to described embodiments, data generated by combination unit 18 may be considered as implementation of tire pressure condition data.

More specifically, data provided to combination unit 18
25 include tire pressure deviation data of at least one of WRA unit 12 and WSA unit 14. Such data will be used to determine tire pressure condition data indicative of tire pressure deviation condition(s) for the vehicle tire. To this end, combination unit 18 may also use data indicating, e.g.,
30 special driving conditions (e.g. driving with snow chains, on

rough roads, on oval track and in a roundabout etc.) provided by dynamic state detector unit 16 and/or further vehicle data.

In general, combination unit 18 determines, based on input data, tire pressure deviation condition(s) for each tire separately or for at least two tires together. In embodiments not illustrated, combination unit 18 determines whether tire pressure indicating data indicate a deviation from a preset, desired and/or required tire pressure. To this end, combination unit 18 may additionally take into account further input data, such as data representing a current driving situation, since such data may influence a decision whether an inappropriate tire pressure deviation exists. Such determination(s) may use threshold comparison(s). Then, an inappropriate tire pressure deviation may be ascertained in the case tire pressure indicating data violate an upper and/or lower threshold (e.g. maximally and minimally, respectively, allowable tire pressure).

If an inappropriate tire pressure deviation condition is detected, combination unit 18 may generate warning data, enable a warning signal and the like to inform about the inappropriate tire pressure deviation condition.

According to embodiments described here, combination unit 18 may be considered as implementation of the step of determining the vehicle tire type and/or the vehicle tire type determination unit or at least a part of such an implementation; in the latter case WSA unit 14 may be considered as implementation of remaining parts.

In addition or as alternative, combination unit 18 may be considered as implementation of the step of determining whether a vehicle tire type can be associated to one of the at least one classified tire type and/or the association determination unit, or at least a part of such an

implementation; in the latter case WSA unit 14 may be considered as implementation of remaining parts.

As set forth above, different tire types may exhibit different tire pressure related behaviors. For optimization, indirect
5 tire pressure monitoring is, according to the present invention, adapted to take into account different tire types. In general, the present invention teaches to determine the type of a vehicle tire to be indirectly tire pressure
10 monitored, to determine whether the determined vehicle tire type can be associated to a previously classified tire type and, in the case such an association can be made, to indirectly tire pressure monitor the vehicle tire in question according to the associated classified tire type.

In the following, embodiments for classification of tire types
15 are explained with reference to Fig. 2.

Tire to be classified were mounted in a test rig for performing force spectrum analysis in order to obtain information on characteristic oscillations of a tested tire. A
20 tire belt oscillates in the tangential direction due to force variations in the contact area with the ground (e.g. when it hits a small obstacle). This force can be measured in the longitudinal direction of the hub, when the tire is mounted in a rig (force equilibrium); see Fig. 2a. The tire also
25 oscillates in a translational motion as a spring-damper system, when compressed by the cleat. This force can be measured in the vertical direction of the hub, see Fig. 2b.

Actual experiments have shown that the first eigenfrequency of the tangential mode and the first eigenfrequency of the translational mode are legible at different velocities. For
30 example, in some experiments first eigenfrequency of the tangential mode is most legible at low velocities (30 km/h),

while the first eigenfrequency of the translational mode is most legible at higher velocities (90 km/h).

In some embodiments, for estimation of power spectrum of the tire forces, force data is down sampled to 400 Hz and
 5 segmented so that each segment contains data from one drum revolution (or one cleat impact). The segments are zero padded to be of length 1024 samples and windowed to eliminate leakage from transients. The periodogram (power spectrum estimate) is calculated according to Welch's method:

$$\Phi(\omega) = \frac{1}{R} \sum_{k=1}^R \Phi_M^{(k)}(\omega)$$

10

where R is the number of segments of length M (here $M = 1024$), and

$$\Phi_M^{(k)}(\omega) = \frac{T}{M} |FFT(F_k(t))|^2$$

where $F_k(t)$ is the k :th segment.

15 Changes in a power spectrum of tire forces may be characterized by the following terms:

Resonance center of gravity f_{cog} :

$$f_{cog} = \frac{\int_{f_{low}}^{f_{high}} f * P_{xx}(f) df}{\int_{f_{low}}^{f_{high}} P_{xx}(f) df},$$

where $P_{xx}(f)$ is the power spectrum for a tire xx and f_{low} and f_{high} indicate lower and upper, respectively, frequencies defining a frequency band of interest.

5 Resonance width w :

$$w = \sqrt{\frac{\int_{f_{low}}^{f_{high}} (f - f_{cog})^2 * P_{xx}(f) df}{\int_{f_{low}}^{f_{high}} P_{xx}(f) df}}$$

The spectral features f_{cog} and w were computed for each power spectrum estimate in order to generate feature trajectory plots. In some embodiments, the following frequency boundaries
10 have been used:

For tire forces in tangential tire direction:

$$f_{low} = 20 \text{ Hz}$$

$$f_{high} = 50 \text{ Hz}$$

For tire forces in tangential tire direction:

15 $f_{low} = 60 \text{ Hz}$

$$f_{high} = 120 \text{ Hz}$$

Analysis of trajectories of spectral features f_{cog} and w for power spectrum estimates of tested tire(s) in view of results obtained from in-vehicle tests of the same tire(s)

demonstrated that a tire force spectrum obtain from a tire in a test rig and, particularly, its spectral features f_{cog} and w is correlated to a wheel speed spectrum of the same tire obtained in in-vehicle experiments and, respectively, to the spectral features f_{cog} and w obtained for the wheel speed spectrum. Such a wheel speed spectrum may be provided by above WSA unit 14.

Fig. 3 shows graphs schematically illustrating wheel speed spectrum data (Fig. 3(a)) and tire force spectrum data (Fig. 3(b)). Each of the illustrated curves includes data obtained for different tire pressures. As can be seen, each of the tire types 368, 362 and 328 have at least comparable wheel speed spectrum data and tire force spectrum data and also have at least comparable pressure dependent behavior. Thus, having information like that illustrated in Fig. 3(b) allows to determine whether a vehicle tire to tire pressure monitored in actual use can be associated to a previously classified tire type (e.g. in the illustrated example, whether a vehicle tire to tire pressure monitored is tire type 368, 362 or 328).

As a result, tire force spectrum analysis of a tire in a test rig, e.g. performed as set forth above, provides information on the behavior of that tire when mounted on a vehicle under actual driving conditions.

Correlation of tire force spectrum obtained from test rig experiments (and its spectral features f_{cog} and w) and wheel speed spectrum (and its spectral features f_{cog} and w) may be, e.g., readily apparent due to comparable features trajectories (in scaled or un-scaled form), e.g. as demonstrated in Fig. 3, and/or obtained on the basis of neuronal network techniques.

On the basis of such correlation(s), it is possible to determine an association of a tire currently used on a vehicle and a tire classified by test rig experiments.

Further, test rig experiments and verification thereof based on in-vehicle tests have shown that tire force spectrum also indicates whether a tire will be easily indirectly tire pressure monitored or not. Even more, it is possible to discriminate in greater detail simplicity and/or complexity of tire pressure monitoring for different tire types, e.g., tires that may be tire pressure monitored with a low, an intermediate or a high degree of complexity.

Such information on a tire type may be used to pre-define parameter setting(s) and/or operation mode(s) to be used in tire pressure monitoring a tire of that type in actual use on a vehicle.

With respect to possible parameter settings it is noted that (for example, as known from e.g wheel/tire spectrum analysis) tires respond differently. For example, stiffer tires may react with reduced/increased amplitude for changed tire pressure and softer tires may react with a frequency shift. With a soft tire the response may be so large that the parameters need to be less sensitive to avoid false alarms. For some tires one or more modules of TPI may even be deactivated to improve robustness. Starting therefrom, it is therefore beneficial, when it comes to different parameter settings for different tires, to employ suitable tire response characteristics for tire to be monitored.

Information obtained in such experimental environment(s) may be provided in form of a database, which may be implemented in and/or associated to the above system 2 (e.g. memory unit 6, WSA unit 14, and/or combination unit 18).

In the following, embodiments of tire pressure monitoring using such a database are described, wherein reference is made to above system 2 for illustration purposes only. Further, it is noted that, since WSA unit 14 is capable of providing

information indicating individual tire pressure, the following procedure may be performed for a single vehicle tire, more than one vehicle tire and up to all vehicle tires.

In use, WSA unit 14 determines wheel speed spectrum data of each vehicle tire to monitored. The wheel speed spectrum data may be determined for, e.g., a specific vehicle speed, a vehicle speed range, a specific wheel speed, a wheel speed range etc.

Further, spectral features f_{cog} and w of the determined wheel speed spectrum data may be determined.

On the basis of the wheel speed spectrum data and/or its spectral features f_{cog} and w , it is ascertained whether the tire classification database comprising information on previously classified tire types includes tire force spectrum data and/or respective spectral features f_{cog} and w of a previously classified tire type to which the wheel speed spectrum data and/or its spectral features f_{cog} and w may be associated.

In the case the database does not include such information (e.g. the vehicle tire to be monitored has not been previously classified, has not been included in the tire classification database etc.), system 2 is normally operated. Normal operation may be based on default parameter setting(s) and/or operation mode(s) for tire pressure monitoring; such default information may be implemented in system 2 itself or may be provided by the tire classification database.

In the latter case, the tire classification database may include information indicating a default classification tire. A default classification tire may be specified on the basis of, e.g., empirical, statistical, model based consideration.

Default parameter setting(s) and/or operation mode(s) for a default classification tire may be defined to provide for an optimal to monitoring of a plurality of different tire types (e.g. tire types common on the market, tire types usually used with the vehicle, tire types recommended for the vehicle etc.).

In the case an association of vehicle tire(s) and a classified tire can be made (particularly, an association of the spectrum data and their spectral features f_{cog} and w), system 2 retrieves from the tire classification database parameter setting(s) and/or operation mode(s) previously defined for tire pressure monitoring of the identified classified tire type. Retrieved parameter setting(s) and/or operation mode(s), which may be as set forth above, are then used by system 2 in actual tire pressure monitoring of vehicle tire(s).

If system 2 determines that the vehicle is equipped with tires of two or more different types, the forgoing procedure (e.g. determination whether a classified tire type can be associated, retrieval of parameter setting(s) and/or operation mode(s), tire pressure monitoring according to retrieved parameter setting(s) and/or operation mode(s)) may performed for each vehicle tire type separately (in parallel or subsequently).

In cases of two or more different vehicle tire types it is also possible to determine a so-called overall vehicle tire type, e.g. a virtual tire accommodating at least some properties of all actual tire types (particularly, their pressure dependent behavior). An overall vehicle tire type may be obtained by computing, on the basis of wheel spectrum data for different actual tire types, wheel spectrum data to be used for identifying a classified tire type to be associated to all actual tire types. Such computed wheel spectrum data

may be derived by means of averaging, median and/or weighting techniques and/or the like.

CLAIMS

1. A method of indirect tire pressure monitoring of tires of a vehicle, comprising the steps of:
- providing a tire classification database indicating at least one classified tire type;
 - determining a vehicle tire type for the vehicle on the basis of vehicle data including information on at least one tire currently used with the vehicle;
 - determining whether the vehicle tire type can be associated to one of the at least one classified tire type; and
 - , in the case an association is determined, monitoring tire pressure according to the associated classified tire type.
2. The method of claim 1, wherein the tire classification database indicates, in association to each of the at least one classified tire type, at least one of at least one parameter setting for tire pressure monitoring and at least one operation mode for tire pressure monitoring; and further comprising a step of retrieving at least one of the at least one parameter setting and at least one operation mode from the tire classification database, wherein the step of tire pressure monitoring is performed according to the retrieved at least one parameter setting and operation mode.
3. The method of claim 1 or 2, wherein the step of determining the vehicle tire type includes a step of determining an overall vehicle tire type for the vehicle.
4. The method of claim 3, wherein the step of tire pressure monitoring is performed for at least two different tires of the vehicle according to the associated classified tire type.
5. The method of claim 1 or 2, wherein the step of determining the vehicle tire type is performed to determine an

individual vehicle tire type for at least two different tires of the vehicle.

6. The method of claim 5, wherein the step of determining whether the vehicle tire type can be associated to one of the
5 at least one classified tire type is performed with respect to each of the at least two different tires.

7. The method of claim 5 or 6, wherein the step of tire pressure monitoring is performed for each of the at least two
10 different tires according to the respectively associated classified tire type.

8. The method of one of the preceding claims, wherein
- the step of determining the vehicle tire type includes a step of determining at least one characteristic of a tire of the vehicle; and
15 - the step of determining whether the vehicle tire type can be associated to one of the at least one classified tire type includes a step of determining whether one of the at least one classified tire type has at least one characteristic being at least comparable with the determined at least one vehicle tire
20 characteristic.

9. The method of one of the preceding claims, wherein the step of determining the vehicle tire type includes a step of wheel speed spectrum analysis to obtain a wheel speed spectrum data for the at least one tire.

25 10. The method of claim 9, wherein the step of determining whether the vehicle tire type can be associated to one of the at least one classified tire type includes a step of determining whether the tire classification database includes data indicating a tire type having tire force spectrum data
30 being at least comparable with the wheel speed spectrum data.

11. The method of claim 9 or 10, wherein the step of wheel spectrum analysis includes a step of determining wheel speed resonance center of gravity data for the at least one tire.

12. The method of claim 11, wherein the step of determining
5 whether the vehicle tire type can be associated to one of the at least one classified tire type includes a step of determining whether the tire classification database includes data indicating a tire type having a tire force resonance center of gravity data being at least comparable with the
10 wheel speed resonance center of gravity data.

13. The method of one of the claims 9 to 12, wherein the step of wheel spectrum analysis includes a step of determining wheel speed resonance width data for the at least one tire.

14. The method of claim 13, wherein step of determining
15 whether the vehicle tire type can be associated to one of the at least one classified tire type includes a step of determining whether the tire classification database includes data indicating a tire type having a tire force resonance width data being at least comparable with the wheel speed
20 resonance width data.

15. The method of one of the preceding claims, further including a step of generating the tire classification database on the basis of testing at least one to be classified tire in a test environment.

25 16. The method of claim 15, wherein the step of generating the tire classification database includes a step of determining, for the at least one to be classified tire, data indicating characteristic tire oscillations.

17. The method of claim 15 or 16, wherein the step of
30 generating the tire classification database includes a step of

determining, for the at least one to be classified tire, data indicating tire oscillations in tangential tire direction.

18. The method of one of the claims 15 to 17, wherein the step of generating the tire classification database includes a
5 step of determining, for the at least one to be classified tire, data indicating tire oscillations in radial tire direction.

19. The method of one of the claims 15 to 18, wherein the step of generating the tire classification database includes a
10 step of determining, for the at least one to be classified tire, tire force spectrum data.

20. The method of one of the claims 15 to 19, wherein the step of generating the tire classification database includes a
15 step of determining, for the at least one to be classified tire, tire force resonance center of gravity data.

21. The method of one of the claims 15 to 20, wherein the step of generating the tire classification database includes a
step of determining, for the at least one to be classified tire, tire force resonance width data.

20 22. The method of claim 17 and
- as far as depending from claim 19, wherein the step of determining tire force spectrum data is based on the data indicating tire oscillations in tangential tire direction;
- as far as depending from claim 20, wherein the step of
25 determining tire force resonance center of gravity data is based on the data indicating tire oscillations in tangential tire direction; and
- as far as depending from claim 21, wherein the step of determining tire force resonance width data is based on the
30 data indicating tire oscillations in tangential tire direction.

23. The method of claim 18 and

- as far as depending from claim 19, wherein the step of determining tire force spectrum data is based on the data indicating tire oscillations in radial tire direction;

5 - as far as depending from claim 20, wherein the step of determining tire force resonance center of gravity data is based on the data indicating tire oscillations in radial tire direction; and

10 - as far as depending from claim 21, wherein the step of determining tire force resonance width data is based on the data indicating tire oscillations in radial tire direction.

24. The method of one of the claims 15 to 23, wherein the step of generating the tire classification database includes a step of determining, for the at least one to be classified

15 tire, at least one of at least one parameter setting for indirect tire pressure monitoring and at least one operation mode for indirect tire pressure monitoring.

25. The method of one of the preceding claims, wherein, in the case the step of determining whether the vehicle tire type can be associated to one of the at least one classified tire

20 type fails, the step of tire pressure monitoring is performed on the basis of at least one of a default parameter setting and a default operation mode.

26. A system for indirect tire pressure monitoring of tires

25 of a vehicle, comprising:

- a tire classification database indicating at least one classified tire type;

- a vehicle tire type determination unit being adapted to determine a vehicle tire type for the vehicle on the basis of

30 vehicle data in including information on at least one tire currently used with the vehicle;

- an association determination unit being adapted to determine whether the vehicle tire type can be associated to one of the

at least one classified tire type; and
- a tire pressure monitoring unit being adapted to, in the case an association is determined, monitor tire pressure according to the associated classified tire type.

5 27. The system of claim 26, wherein the tire classification database indicates, in association to each of the at least one classified tire type, at least one of at least one parameter setting for tire pressure monitoring and at least one operation mode for tire pressure monitoring; and further
10 comprising a retrieving unit being adapted to retrieve at least one of the at least one parameter setting and at least one operation mode from the tire classification database, wherein the tire pressure monitoring unit is adapted to perform tire pressure monitoring according to the retrieved at
15 least one parameter setting and operation mode.

28. The system of claim 26 of 27, wherein the vehicle tire type determination unit is adapted to determine an overall vehicle tire type for the vehicle.

29. The system of claim 28, wherein the tire pressure
20 monitoring unit is adapted to perform tire pressure monitoring for at least two different tires of the vehicle according to the associated classified tire type.

30. The system of claim 26 or 27, wherein the vehicle tire type determination unit is adapted to determine an individual
25 vehicle tire type for at least two different tires of the vehicle.

31. The system of claim 30, wherein the association determination unit is adapted to determine whether the vehicle tire type can be associated to one of the at least one
30 classified tire type with respect to each of the at least two different tires.

32. The system of claim 30 or 31, wherein the tire pressure monitoring unit is adapted to perform tire pressure monitoring for each of the at least two different tires according to the respectively associated classified tire type.

5 33. The system of one of the claims 26 to 32, wherein
- the vehicle tire type determination unit is adapted to
determine at least one characteristic of a tire of the
vehicle; and
- the association determination unit is adapted to determine
10 whether one of the at least one classified tire type has at
least one characteristic being at least comparable with the
determined at least one vehicle tire characteristic.

34. The system of one of the claims 26 to 33, wherein the
vehicle tire type determination unit is adapted to perform
15 wheel speed spectrum analysis to obtain a wheel speed spectrum
data for the at least one tire.

35. The system of claim 34, wherein the association
determination unit is adapted to determine whether the tire
classification database includes data indicating a tire type
20 having tire force spectrum data being at least comparable with
the wheel speed spectrum data.

36. The system of claim 34 or 35, wherein the association
determination unit is adapted to determine wheel speed
resonance center of gravity data for the at least one tire.

25 37. The system of claim 36, wherein the vehicle tire type
determination unit is adapted to determine whether the tire
classification database includes data indicating a tire type
having a tire force resonance center of gravity data being at
least comparable with the wheel speed resonance center of
30 gravity data.

38. The system of one of the claims 34 to 37, wherein the association determination unit is adapted to determining wheel speed resonance width data for the at least one tire.

39. The system of claim 38, wherein the vehicle tire type determination unit is adapted to determine whether the tire classification database includes data indicating a tire type having a tire force resonance width data being at least comparable with the wheel speed resonance width data.

40. The system of one of the claims 26 to 39, further including means being adapted to carry out the steps of one of the claims 15 to 24.

41. The system of one of the claims 26 to 40, wherein, in the case the vehicle tire type can be associated to one of the at least one classified tire type fails, the tire pressure monitoring unit is adapted to perform tire pressure monitoring on the basis of at least one of a default parameter setting and a default operation mode.

42. A computer program product for an indirect tire pressure monitoring for detecting tire pressure deviation in tires of a vehicle, the computer program product comprising program code for carrying out, when executed on a processing system, the steps of:

- providing a tire classification database indicating at least one classified tire type;
- determining a vehicle tire type for the vehicle on the basis of vehicle data in including information on at least one tire currently used with the vehicle;
- determining whether the vehicle tire type can be associated to one of the at least one classified tire type; and
- , in the case an association is determined, monitoring tire pressure according to the associated classified tire type.

43. The computer program product of claim 42, further comprising program code for carrying out, when executed on a processing system, the steps defined of at least one of the claims 1 to 25.

- 5 44. The computer program product of claim 42 or 43, being stored on a computer-readable storage medium or in a computer-readable storage device.

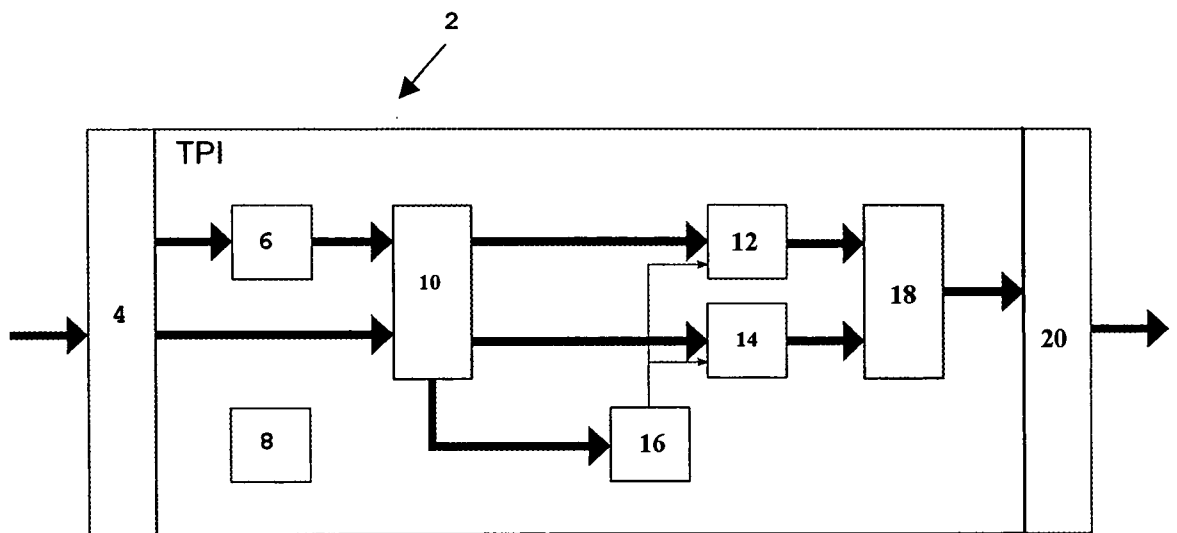
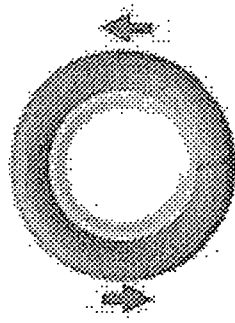
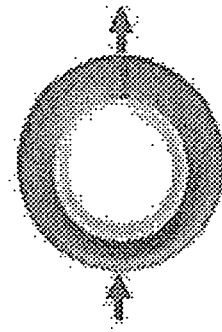


Fig. 1

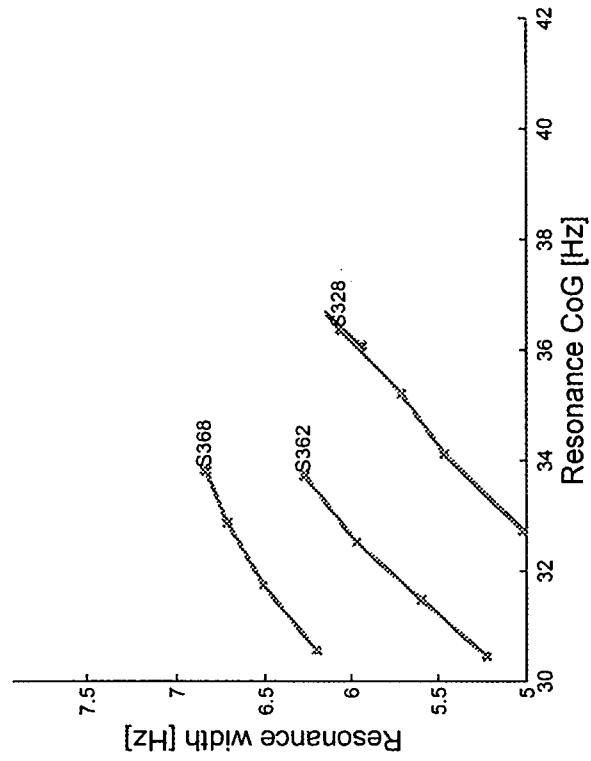


(a) Tangential force

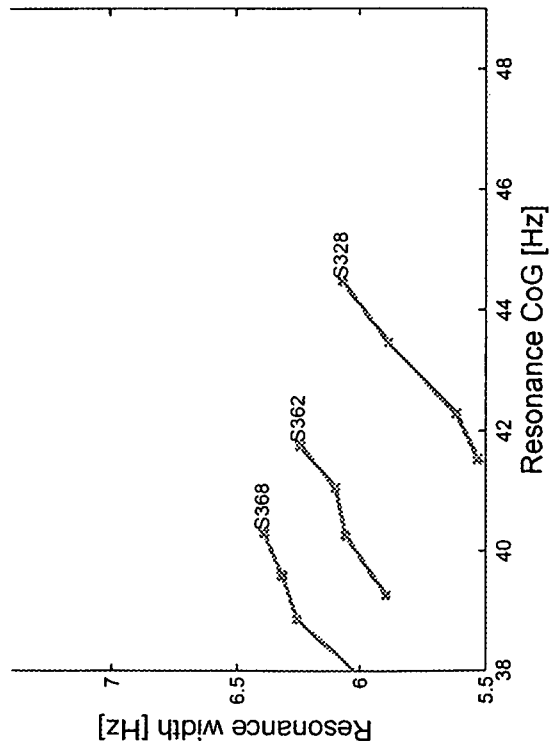


(b) Translational force

Fig. 2



(b)



(a)

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2007/002366

A. CLASSIFICATION OF SUBJECT MATTER
INV. B60C23/06

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B60C

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 557 552 A (NAITO TOSHIHARU [JP] ET AL) 17 September 1996 (1996-09-17)	24-35, 38, 40-44
Y	column 5, line 14 - column 10, line 6	12, 13, 20-23, 36-38
A	column 11, line 8 - column 13, line 21 figures 1-31	14, 39
Y	US 5 553 491 A (NAITO TOSHIHARU [JP] ET AL) 10 September 1996 (1996-09-10)	12, 20, 22, 23, 36, 37
	column 8, line 38 - column 9, line 31 figures 79-92	
Y	DE 198 59 225 A1 (AISIN SEIKI [JP]) 1 July 1999 (1999-07-01)	13, 21, 38
	column 3, line 1 - line 42 column 5, line 29 - line 50 figures 1,7-9	

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

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P document published prior to the international filing date but later than the priority date claimed

T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

X document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

Y document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

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Date of the actual completion of the international search

14 November 2007

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2007/002366

Patent document cited in search report		Publication date		Patent family member(s)		Publication date
US 5557552	A	17-09-1996	DE	4409816 A1		29-09-1994
			JP	3289375 B2		04-06-2002
			JP	6278419 A		04-10-1994
<hr/>						
US 5553491	A	10-09-1996	NONE			
<hr/>						
DE 19859225	A1	01-07-1999	US	6109099 A		29-08-2000
<hr/>						