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(54) **Title:** TRACK SYSTEM UTILIZING A NON-PNEUMATIC TIRE

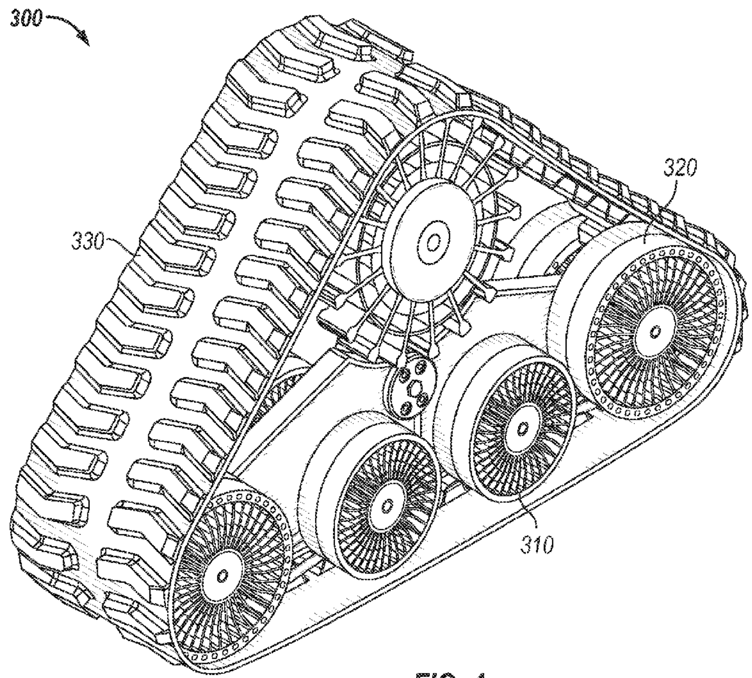

FIG. 4

(57) **Abstract:** A track system, the track system including a non-pneumatic tire, the non-pneumatic tire including an annular beam and an annular support extending radially inward from the annular beam, the annular support being configured to develop tension forces when the non-pneumatic tire is loaded to the design load. The track system further including a dual tension system for a track.

WO 2024/258564 A1

[Continued on next page]

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TRACK SYSTEM UTILIZING A NON-PNEUMATIC TIRE

FIELD OF THE INVENTION

[0001] This disclosure relates to non-pneumatic tires for track systems, and, more generally, to vehicles such as agricultural vehicles or industrial vehicles.

BACKGROUND OF THE INVENTION

[0002] Track systems are used in a variety of industries, particularly in off-road vehicles needing high traction. These can include construction vehicles (loaders, excavators, etc.) and military vehicles (tanks) and agricultural vehicles (tractors, sprayers, etc). Track systems may enhance traction and/or flotation on soft, slippery, and/or irregular grounds.

[0003] The use of suspension systems on track vehicles may be expensive and complex. Due to their very nature, track systems employ a track that wraps around a plurality of wheels. Mounting a suspension system on each wheel may increase complexity, cost, and may reduce system reliability.

[0004] US Patent Application Publication 2020/0277012, owned by the current applicant and included herein by reference, shows a compliant wheel in the idler position. This compliant wheel may reduce impact forces passed to the track suspension frame by acting like a shock absorber of sorts. As such, the performance of the track system may be enhanced.

[0005] However, one of the challenges faced in the above application is the requirement to resist track system. Track system forces may further be increased during braking and accelerating. Having a deformable wheel capable of sustaining these forces without collapsing may be difficult.

[0006] WO 2022/104481, also owned by the current applicant and included herein by reference, discloses a track tensioning system. This track tensioning system comprises springs that support both idler wheels. It is therefore a dual track tensioning system. This system may be efficient for reducing the required function of a compliant wheel in the idler wheel. It may enable the use of a more rigid wheel that still deforms under impact. It may also reduce the track tension forces developed during acceleration and braking. Therefore, a dual tension system in a track system may enable complaint wheels.

[0007] To be most efficient in shock absorption, a track system may benefit by having complaint wheels not only in the idler wheel position, but also in the midroller position. This, however, is a challenge because the midroller supports the majority (if not all) the weight of the vehicle. Midrollers may be smaller than idler wheels, meaning that even small deflections may be large percentages of the radius of the wheel. Designing a large enough compliance within a small design window could be challenging.

[0008] Optimization of track system design has incrementally improved the performance of track systems by reducing weight and increasing robustness. The rate of improvement of track system performance has declined over time as the theoretical asymptotic limits of the combination of current technology and knowhow are reached. The current disclosure creates a new asymptote for track system performance by providing a non-pneumatic tire in an idler wheel position as well as a non-pneumatic tire in a midroller position. Further, total system performance may be enhanced by combining this with a track system comprising a dual tension system.

SUMMARY OF THE INVENTION

[0009] Aspects and advantages of the invention will be set forth in part in the following description, or may be obvious from the description, or may be learned through practice of the invention.

[0010] According to an aspect of the invention, there is provided a non-pneumatic tire for use as a midroller in a track system, the non-pneumatic tire comprising an annular beam, further comprising an annular support extending radially inward from the annular beam, for which a deflection at a contact patch of the annular beam is no less than 0.5% of the diameter of the annular beam when the non-pneumatic tire is loaded to a design load, the annular support being configured to develop tension forces when the non-pneumatic tire is loaded to the design load. In some cases, the deflection may be no less than 1% of the diameter; in other cases, 2%. In such an embodiment the diameter is measured to the outer extent of the annular beam.

[0011] According to an aspect of the invention, there is provided a track system, the track system comprising a non-pneumatic tire, the non-pneumatic tire comprising an annular beam, further comprising an annular support extending radially inward from the annular beam, the annular support being configured to develop tension forces when the non-pneumatic tire is loaded to the design load. The track system further comprises a dual tension system for a track.

[0012] According to an aspect of the invention, there is provided a non-pneumatic tire for use in a track system, the non-pneumatic tire comprising an annular beam, further comprising an annular support extending radially inward from the annular beam, the annular support being configured to develop tension forces when the non-pneumatic tire is loaded to the design load. An initial secant vertical stiffness of the non-pneumatic tire measured at the design load is at least twice that of a secant vertical stiffness measured at 2.7 times the design load, and in other cases the secant vertical stiffness is at least three times, and in other cases, even more.

[0013] According to an aspect of the invention, there is provided a non-pneumatic tire for use in a track system, the non-pneumatic tire comprising an annular beam, the annular beam comprising a reinforcing ring extending in the circumferential direction, the non-pneumatic tire further comprising an annular support extending radially inward from the annular beam, the annular support being configured to develop pre-tension forces after the non-pneumatic tire is formed. The non-pneumatic tire comprises a thermoplastic elastomer.

[0014] In yet another aspect of the invention, a track system having a non-pneumatic wheel, where the wheel comprises a tire portion and a hub portion. In this embodiment the non-pneumatic wheel has a wheel mass divided by a tire outer diameter divided by a max tire width should be no more than 0.0002 kg / mm^2: in other cases no more than 0.00015 kg / mm^2, and in other cases, even less. Here the wheel mass is calculated by adding the mass of the hub and outer tire portion of the wheel.

[0015] These and other features, aspects and advantages of the present invention will become better understood with reference to the following description and appended claims. The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] A full and enabling disclosure of the present invention, including the best mode thereof, directed to one of ordinary skill in the art, is set forth in the specification, which makes reference to the appended figures, in which:

[0017] Figure 1 is an exemplary example of an NPT used in a track system.

[0018] Figure 2 is an exemplary example of an NPT used in a track system having spokes that intersect one or a plurality of other ones of the spokes.

[0019] Figure 3 is an exemplary example of an NPT used in a track system.

[0020] Figure 4 is a track system comprising exemplary examples of NPTs.

[0021] Figure 5 is a track system comprising and exemplary example of an NPT. The track system comprises a dual-tensioning system for a track.

[0022] Figure 6 is a graph showing load vs. deflection of three midroller NPTs.

[0023] Figure 7 is a graph showing load vs. deflection of three idler wheel NPTs.

[0024] Figure 8 shows a deformed Finite Element Model (FEM) of an exemplary example of an NPT, loaded to an impact load.

[0025] Figure 9 is a photograph of an NPT in a track system, having wheels in accordance with an embodiment of the invention, when subjected to an impact load.

[0026] Figure 10 is a track system dynamic modeling result of a midroller stiffness vs midroller impact force transferred to the track system frame transiting an obstacle at a speed of 3 kph.

[0027] Figure 11 is an example of a reinforcing ring used in an annular beam of an NPT.

[0028] Figure 12 is a close-up image of a reinforcing ring.

[0029] Figure 13 is a close-up image of a reinforcing ring.

[0030] Figure 14 shows a reinforcing ring comprising a pin for fixation inside a mold.

[0031] Figure 15 shows another exemplary example of a reinforcing ring.

[0032] Figure 16 shows load vs. deflection for NPTs with and without a reinforcing ring.

[0033] Figure 17 shows creep performance of NPTs with and without a reinforcing ring.

[0034] Figure 18 is an NPT comprising a tread.

[0035] The use of identical or similar reference numerals in different figures denotes identical or similar features.

DETAILED DESCRIPTION OF THE INVENTION

[0036] The present invention provides a compliant non-pneumatic tire for an endless track system for a vehicle. For purposes of describing the invention, reference now will be made in detail to embodiments and/or methods of the invention, one or more examples of which are illustrated in or with the drawings. Each example is provided by way of explanation of the invention, not limitation of the invention. In fact, it will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the scope or spirit of the invention. For instance, features or steps illustrated or described as part of one embodiment, can be used with another embodiment or steps to yield a still further embodiments or methods. Thus, it is intended that the present invention covers such modifications and variations as come within the scope of the appended claims and their equivalents.

[0037] The following terms are defined as follows for this disclosure, with material properties referring to those at ambient temperature, or 23°C where a specific temperature is required, unless otherwise noted:

[0038] “Radial” (R), “axial” (Y), “circumferential (θ) refer to tire coordinates shown in Figure 1.

[0039] “Hub” refers to any structure for supporting the tire and capable of attachment to a vehicle axis.

[0040] “Vertical”(Z), “lateral” (Y) and “longitudinal” (X) refer to tire and vehicle coordinates as defined in Figure 1.

[0041] When referring to an unreinforced thermoplastic elastomer, “modulus” means Young’s tensile modulus of elasticity measured per ASTM D638. The tensile modulus may be calculated as the secant modulus at a tensile strain of 0.5%.

[0042] When referring to a reinforced thermoplastic elastomer, “modulus” means Young’s tensile modulus of elasticity measured per ASTM D638. The tensile modulus may be calculated as the secant modulus at a tensile strain of 0.2%.

[0043] “Design Load” of a tire is operating load of the tire when the track system is loaded to a Maximum Load.

[0044] “Diameter” of a tire is measured at the outer extent of the annular beam inclusive of any tread material that may be present.

[0045] Tire vertical force vs. deflection and footprint measurements may be performed according to SAEJ2704.

[0046] “Maximum Load” of the track system is the maximum permissible load assigned to a track system by the manufacturer, or where the manufacturer does not specify a Maximum Load, as specified by the designer of the track system, or where the manufacturer or designer does not specify a Maximum Load, as specified by the distributor.

[0047] "Midroller" refers to a wheel position between the idler wheels in a track system as shown in Figure 4.

[0048] "Idler wheel" refers to a wheel position on the front and back ends in a track system as shown in Figure 4, the "front" and "back" referring to the potential directions of travel of the track.

[0049] Figure 1 shows a non-pneumatic tire 100 for a track system according to an aspect of the invention. A cylindrical coordinate system 140 defined by the invention is shown, along with a corresponding cartesian coordinate system 150. The "X" or longitudinal direction may be considered the direction of travel.

[0050] The tire has a circumferential beam 110, with an annular support 120 that extends radially inward from the beam. A hub 130 is positioned radially inward from the annular support. The tire rotates around the Y axis.

[0051] In this exemplary embodiment, the annular support comprises a spoke structure comprising a plurality of spokes in which each spoke of the plurality of spokes extends radially from the hub to the annular beam. In at least one embodiment, each tire has a first lateral side and a second lateral side opposite the first lateral side forming the axial extents of the tire and each of the spokes of the plurality of spokes extend from the first lateral side to the second lateral side.

[0052] Other embodiments are possible, however, in which the annular support comprises spokes that intersect one or a plurality of other ones of the spokes. Figure 2 shows an example of an annular support having spokes 820 that are not continuous from the annular beam 810 to the hub 830, thereby creating two rows of rectangular openings. Each spoke 820 is comprised of a radially outer portion 822 and a radially adjacent radially inner portion 826. Each spoke 820 is adjoined to a circumferentially adjacent spoke by a flange 824 positioned between the hub 830 and the annular support 820. Thus each spoke 820, a circumferentially adjacent spoke, the hub 830 and annular beam 810 form rectangular openings within the support structure. Furthermore, such a geometry creates an annular support with a spoke length that is effectively much shorter. As such, the critical buckling load of one spoke may be much higher. For such complex geometries, the inventors have found that finite element analysis is a preferred method by which to predict and design a load vs. deflection characteristic according to the disclosures herein. Still other embodiments could include cell structures comprising rectangular openings, triangular openings, hexagonal openings, or any suitable configuration in the annular support.

[0053] Figure 3 shows an idler wheel 200 according to aspects of the invention. The idler wheel comprises an annular beam 210 which may comprise a web structure 240. The web structure may comprise circular, oval, or elliptical openings. These openings may extend from one axial extent of the annular beam to the other axial extent.

[0054] A track system 300 is shown in Figure 4. The track system comprises a non-pneumatic tire in a midroller position 310 and a non-pneumatic tire in an idler wheel position 320. For clarity and to employ industry standard terms, "midroller" will henceforth refer to a non-pneumatic tire in the midroller position, and "idler wheel" will refer to a non-pneumatic tire in the idler wheel position, unless otherwise noted.

[0055] The track system further comprises a track 330. The track has a pretension force which is reacted by the idler wheels. The track system carries a weight which is supported by the midrollers and idler wheels as they roll on the radially inward side of the track. The track system may be configured such that most or all the load is carried by the midrollers when in operation on flat ground at a design load.

[0056] Figure 5 shows the track system from an axial perspective. This exemplary embodiment further comprises a twin tensioning system, similar to that described in PCT publication WO 2022/104481 A1 describing a Track System for Traction of a Vehicle, incorporated herein by reference. There is a first tensioning element 340 and a second tensioning element 350. These tensioning elements are configured such that the track system may be operated in either longitudinal direction. Furthermore, the tensioning system is configured such that rapid deceleration of the track system does not result in high track tension force. The tension force during deceleration may be the same whether the track system is traveling in the +X or the -X direction.

[0057] Figure 5 further shows a track system frame 360. This frame must be designed of sufficient strength to withstand not only a design load during normal operation but also impacts and other punctual loads to which the track system is anticipated to be subjected to.

[0058] In some aspects of the invention, the use of a twin tensioning system may enable or enhance the use of a non-pneumatic, deformable tire as an idler wheel. While deformable, the idler wheel must still be able to resist the tension force in the track. Under certain braking conditions, the tension force in a single tension element track system may be so high that the use of a deformable idler wheel becomes very difficult. Therefore, in some cases, a twin tension system and deformable idler wheels may be combined.

[0059] Example 1.

[0060] NPTs designed according to Figures 1 and 3 were reduced to practice and tested in a battery of lab and on-vehicle tests. The NPTs were further designed to be injection molded with a single elastomeric thermoplastic. Several different thermoplastic materials were prototyped. Several figures and tables will now disclose results obtained. These results were, in part, surprising and unexpected. Not surprising, these results form the basis for several aspects of the invention.

[0061] Idler wheels and midrollers were each prototyped with three materials. For reference, the wheel dimensions are provided in Table 1 below:

[0062] Table 1. Wheel dimensions in exemplary embodiments tested.

	Tire diameter (mm)	Hub diameter (mm)	Width (mm)
Midroller	200	70	90
Idler Wheel	265	70	90

[0063] For both midroller and idler wheel, tires were produced having three levels of elastomeric material modulus:

[0064] - Midroller A and Idler Wheel A: 1600 MPa

[0065] - Midroller B and Idler Wheel B: 290 MPa

[0066] - Midroller C and Idler Wheel C: 180 MPa

[0067] Elastomers from any suitable family may be employed. This may include thermoplastic elastomers such as co-polymers. This may include products from DuPont (Hytrel) or from DSM (Arnitel), or other similar products. Other elastomer families may include certain nylon resins with softening agents added, such as impact modifiers (EPDM rubber or the like). Other elastomer families could include TPUs, such as BASF's Ellastolan.

[0068] For the specific track system that was prototyped, the midroller carries most of the load at the design load. The idler wheels carry minimal load when in normal operation on flat ground. In specific embodiments, the idler wheels carry less than 10% of the design load. Idler wheels may be functionally important in shock absorption, for example, when the track system encounters obstacles.

[0069] For this specific midroller size and this specific track system, 2200 N is a design load on one midroller when the track system is operating at the design load. The midroller must support this load during normal operation on flat ground. 5940 N is an impact load on one midroller when the track system encounters an obstacle, such as a rock or a curb or a railroad track. This load is punctual and is equal to 2.7 times the nominal load. Obviously, impact loads that are less than 5940 N can and do often occur. The inventors, however, have determined that system operation may be characterized by making the simplifying assumption that 2.7 times the design load is characteristic of larger impact loads the system will often encounter.

[0070] Suspension systems comprising springs and shock absorbers may be expensive and complex in a track system. For this reason, track systems may have no suspension system other than the idler wheels, midrollers, and track itself. Having deformable wheels may greatly improve the inherent shock absorbing capability of a track system that does not have a dedicated suspension system.

[0071] Wheels that deform may greatly reduce shock loading to the frame of the track system. In doing so, deformable wheels may improve the fatigue life of the system and/or enable a lighter weight, lower cost frame to be designed.

[0072] Furthermore, deformable wheels in a track system may reduce the pressure that the wheel exerts on the radially inward surface of the track. A deformable, compliant wheel may develop a larger contact area, thereby reducing pressure at a given load. As those skilled in the art of tire design know, energy loss in an elastomer directly relates to the change in strain energy as the elastomer is subjected to a cyclic stress. By reducing the stress applied by the wheel to the track, the hysteretic energy loss of the track may be reduced. These possible benefits of deformable wheels were studied and measured with the three levels of stiffness of Tires A, B. and C.

[0073] All on-vehicle testing was done as a set, meaning that both idler wheel and midroller had the same material. Thus, Midroller A was always tested with idler wheel A, and so on.

[0074] Figure 6 shows a load vs. deflection plot of these three midrollers. The three levels of elastomer stiffness result in three different load vs. deflection curves. Tires B and C exhibit non-linear behavior, whereas Tire A is quite linear and much stiffer over the pertinent range of load. In the embodiments herein, a linear relationship between load vs deflection is defined as having a R^2 coefficient from a linear regression analysis of greater than 0.98.

[0075] Figure 7 shows a load vs. deflection plot of these three idler wheels. As with the midrollers, the three levels of elastomer stiffness result in three different load vs. deflection curves. Similar to the midroller, Tire A is linear and much stiffer, while B and C show non-linear behavior.

[0076] The non-linear behavior of Tires B and C is explained by Figure 8, in combination with a comprehension of Euler's column buckling mechanics. Figure 8 shows a deformed FEA model of midroller tire B, when loaded to the impact load of 5940 N. The annular support comprises spokes 320 away from the contact area and spokes 310 in the contact area. Spokes away from the contact area develop tension forces. Spokes in the contact area are deformed in bending at this load. In fact, these spokes behave as post-buckled columns. Before the critical bucking load, spokes in the contact area are stiff. After the buckling load, their load-carrying contribution is reduced. Hence, the load vs. deflection of the tire is non-linear.

[0077] Euler's critical buckling load formula for a column fixed at both ends is shown below in Equation 1:

$$F_C = \frac{4\pi^2 EI}{L^2} \tag{1}$$

[0078] For our case of a rectangular spoke cross section as the column the spoke moment of inertia is determined by Equation 2:

$$I = \frac{1}{12}\, wt^3 \tag{2}$$

[0079] Where Fc is buckling load, E is the spoke modulus, I is the spoke moment of inertia in the R-T plane, w is the spoke width, t is the spoke thickness, and L is the distance from spoke intersection with annular beam to intersection with hub.

[0080] For the geometry and material of the midroller Tire B, the critical buckling load, Fc, of one spoke is approximately 1000 N. In this particular embodiment the spoke length is 52 mm with a width of 80 mm and a thickness of 3.3 mm. For material B, E = 290 MPa. Thus Fc can be determined to be approximately 1000 N. With four post-buckled spokes at 4000N, the tire stiffness becomes much lower as the total tire load exceeds 4000N.

[0081] As a person of ordinary skill in the art would observe from equations 1 and 2 above, achievement of the desired buckling load can be obtained through variation of the spoke thickness or aspect ratio of the spokes, inter alia.

[0082] With Tire B midroller, the secant vertical stiffness at a load of 2200 N is 1560 N /mm. At the impact load of 5940N, the secant stiffness 960 N/mm. In this exemplary case, the secant stiffness at the design load is 1.6 times as large as the secant stiffness at the impact load.

[0083] Extensive testing by the inventors has shown that a secant stiffness of the midroller at the design load should be at least 1.4 times that of a secant stiffness at the impact load. In other cases, at least 1.8 times, and in other cases, even more.

[0084] As previously mentioned, the idler wheel carries relatively little to no load when under normal operation on a flat surface. Its primary function is to simply support track tension while carrying transient loads during impacts as the vehicle navigates non-flat terrain or encountering obstacles. Therefore, there is no vertical design load, per se, for the idler wheel. Nevertheless, the inventors have determined that the non-linear behavior of Tires B and C in Figure 7 is very beneficial for reducing impact loading. Instead of being defined relative to load, the idler wheel secant vertical stiffness may be defined according to displacement.

[0085] For the idler wheel, an initial secant stiffness is measured at a small displacement equal to 0.5% of the idler wheel diameter. The idler wheel impact displacement can be estimated as 5% of the idler wheel diameter. Extensive testing by the inventors has shown that a secant stiffness of the idler at a displacement of 0.5% of the diameter should be at least 2.0 times that of a secant stiffness at a displacement of 5% of the diameter. In other cases, at least 2.6 times, and in other cases, even more.

[0086] A track system may comprise a compliant midroller and a rigid idler wheel. Conversely, a track system may comprise a complaint idler wheel and a rigid midroller. Aspects of this invention are meant to encompass both of these configurations, as well as the exemplary embodiment tested here, in which both midroller and idler wheel were compliant.

[0087] As previously stated, one advantage of a complaint wheel is that shock loads to the track system may be reduced, compared to a rigid wheel. The inventors studied this with a track system that was reduced to practice and instrumented with strain gauges installed in key high stress areas of the system frame. Then, using an engineered "bump" or obstacle, strain gauge measurements were made using a step-speed test. This was performed with the same track system, but mounted with Tire A, Tire B, and Tire C. For all tests, both idler wheel and midrollers were tested using the same material.

[0088] Results are shown in Table 2 below.

[0089] Table 2. Undercarriage frame strain gauge measurement vs. speed at 50% payload.

Speed (kph)	Tire A	Tire B	Tire C
1	92%	75%	74%
2	**102**%	93%	83%
3		96%	Wheel collapse
4		91%	
5		92%	
6		**101**%	

[0090] 100% strain gauge measurement = maximum design value for fatigue.

[0091] Figure 9 is a photograph of test apparatus used to gather data for Table 2. Idler wheel 310 and midroller 320 both deform during contact. In the Figure, the midroller is clearly seen deforming to approximately the impact load as the track and midroller envelop an obstacle 400. Spokes 222 are post-buckled in the contact area and under tension 221 away from the contact area.

[0092] As expected, strain gauge measurements generally increased with respect to speed. Also as expected, Tire A developed highest strain gauge measurements, beginning at lowest speeds. In fact, at 2 kph, Tire A resulted in a track system frame strain gauge measurement that was slightly higher than the maximum design value acceptable for fatigue. This level of strain was not attained with Tire B until a speed of 6 kph was used. Tire A was practically a rigid wheel, as evidenced by the load vs. deflection measurement.

Thus, Tire B gave a very large system benefit - the system could be operated at about 3 times the speed, compared to a rigid wheel.

[0093] The results when using Tire C, however, were surprising. Tire B expectedly gave the lowest strain gauge measurements at 1 and 2 kph. However, at 3 kph the midroller Tire C collapsed - the tire was too compliant and could not support the impact load such that annular beam is compressed against the spokes and hub. Thus, the midroller Tire C was not measured for speeds of 3 kph and above. Tire C was less performant than Tire B, even though it was more compliant.

[0094] This behavior is surprising as one of ordinary skill in the art expects Tire C to perform best. Study of the load vs. deflection graph and calculating the impact load requirements provides an understanding of why, in hindsight, this outcome occurred. Midroller Tire C required a large deflection of over 15 mm to support the impact load of 5940 N. In actual transient operation, the spoke structure collapsed. Repeated impacts with this deformation be expected to cause tire failure and perhaps frame fatigue issues. Therefore, Tire B represented a surprising optimum design for the midroller and idler wheel set.

[0095] Further study of the experimental embodiments by the inventors has lead to the discovery of the link between this attribute a specific midroller behavior. The midroller deflection at the design load is desirable to be within a specific range of the tire diameter. It was discovered if the deflection at the design load as a percentage of the diameter is very small, such as Tire A (0.2%) for example, then the tire is too stiff. If this ratio is too large, such as Tire C (1.5%) for example, then the tire is too compliant.

[0096] The inventors have determined that a midroller deflection should be at least 0.5% and no more than 1.3% of the tire diameter when loaded to a design load and in other cases, at least 0.8% and no more than 1.3%.

[0097] Using an electric track system, the required power to operate at a steady state speed on level ground was measured for tire set A, B, and C, provided in Table 3. As with the previously reported empirical data, the data below was obtained when idler wheel and midroller had the same material.

[0098] Table 3. Power required to operate at steady state speed on level ground.

Tire Version	Power consumption, one track system (Watts)	Midroller/Track Pressure From FEA

Tire A	100%	100%
Tire B	58%	83%
Tire C	68%	66%

[0099] The results above are surprising because Tire B was the lowest value. A person of ordinary skill in the art would expect that power consumption by the entire track system would be lowest for Tire C, as this lowest stiffness elastomer gave the lowest track stress.

[00100] Upon further study it was discovered that the reason for the higher power loss for Tire C was that tire intrinsic power consumption increased more than the track consumption had decreased. Tire C midroller deflection at the design load is about twice as high for Tire C as Tire B. This supports a deduction that the intrinsic energy loss was as much as four times higher. These results support the stiffness characteristics of Tire B are superior to that of Tire A or Tire C.

[00101] Another benefit of elastomeric compliant midrollers and idler wheels is weight. The specific gravity of an elastomer may be about 1.1, whereas steel is 7.8. Therefore, intrinsic wheel mass may be reduced compared to a steel wheel. The track system frame is designed to resist the transient, but significant forces that occurs due to punctual impact loading. The impacts upon a steel wheel are transferred directly to the frame that supports the midrollers. Midroller and idlerwheel compliance enables a lower weight track system frame by reducing the punctual loading that would be endured by the system.

[00102] Example 2.

[00103] The inventors designed a standard track system using prior art metal wheels, with corresponding prior art design rules. The use of compliant wheels in the track system results in weight reduction from two sources, intrinsic weight reduction from the use of lighter weight wheels and extrinsic weight reduction by enabling lighter weight components in the design of the track frame itself which is permitted by reduced impact loads during operation such as depicted occurring in Figure 9. The inventors compared track system mass of this prior art system to the mass obtained with aspects of the current invention. Results are shown in Table 4.

[00104] Table 4. Weight reduction enabled of track system.

Track system description	Weight Reduction
A: Metal wheels, steel undercarriage components using prior art	Reference
B: Metal wheels, undercarriage with aluminum and steel components	-7%
C: Elastomer wheels, undercarriage with aluminum and steel components	-16%

[00105] Table 4 shows that a 7% mass reduction was achieved due to aluminum components in the undercarriage. Of course, if this undercarriage had been tested with rigid wheels, it would not have had the required strength to meet endurance requirements because the metal wheels lack of compliance allows for transient impact loads to excessively load the undercarriage components.

[00106] A 16% mass reduction was achieved by adding compliant wheels. Complaint wheels with elastomer wheels were successfully tested in field endurance testing.

[00107] The inventors found the architecture of an elastomeric non-pneumatic tire with an annular beam and an annular support that develops tension forces to be surprisingly efficient in terms of mass reduction. The inventors have further found that this benefit can be characterized as a ratio equal to the tire mass divided by the tire outer diameter divided by the tire width. This gives an equivalent mass density.

[00108] To provide a suitable mass reduction, the inventors have found that a wheel mass divided by a tire outer diameter divided by a max tire width should be no more than 0.0002 kg / mm^2: in other cases no more than 0.00015 kg / mm^2, and in other cases, even less. Here the wheel mass is calculated by adding the mass of the hub and outer tire portion of the wheel.

[00109] The inventors have performed computer simulations of the dynamic performance of a track system comprising the stiffness characteristics of midroller and idler wheels A, B, and C. Further, the inventors included a reference metallic tire. This system-level simulation could extract maximum impact loads at the axle of the midroller when the system traversed an obstacle of the same geometry shown in Figure 9. Simulation results are shown in Figure 10 which depict the track system comprising wheels of elastomer C, B, and A with metal reference from left to right on the chart from most compliant to least compliant.

[00110] Figure 10 shows a direct correlation between transmitted impact force and wheel stiffness. This further validated the empirical strain gauge measurements noted earlier. Compliant wheels reduced shock loading, which resulted in lower strain and stress in the undercarriage frame.

[00111] As previously stated, midroller and idler wheels A, B, and C used a monoelastomer architecture. The inventors have found that, in certain cases, it may be advantageous to include a reinforcing ring extended in the circumferential direction of the annular beam. Such reinforcement may improve certain performances.

[00112] Figure 11 shows an exemplary embodiment of a reinforcing ring 500. The reinforcing ring comprises a dovetail geometry 510 on the radially outward surface and a dovetail geometry 520 on the radially inward surface. A protruding surface, extending away from the reinforcing ring in the radial outward or radially inward direction form the dovetail geometry 510 or 520, with each circumferentially facing wall of the dovetail geometry extending toward the adjacent facing wall of the dovetail geometry circumferentially adjacent to it. A locating pin 530 extends in an axial direction which may contact a mold surface and serve to position and stabilize the reinforcing ring in a mold by contacting the lateral surfaces of the mold cavity for the annular beam into which the reinforcing ring is placed. When the mold cavity is filled with the material comprising the annular beam, the material is allowed to pass around and envelope the reinforcing ring, with exception, perhaps, to the points of contact the reinforcing ring 500 has with the mold surfaces. The locating pins maintain the position of the ring within the mold. A pin 540 and a pin 550 may be configured with male and female axial extents respectively, thereby permitting two reinforcing rings to connect.

[00113] Radial extending locating pins 560 located on the radial extent of the reinforcing ring 500. In this particular embodiment, the radially extending locating pins 560 extend radially inwardfrom the radially inward facing radial extent of the reinforcing ring 500. Similar to the laterally positioned locating pin 530, the radial locating pin maintains the reinforcing ring 500 in position within the mold particularly during the injection of the material into the mold.

[00114] The wall thickness of the reinforcing ring was between 1 mm and 2 mm. The scope of this invention is meant to encompass reinforcing ring thicknesses between 0.5 mm to 10 mm. Thicker rings may be used for larger tires; thinner rings may be used for smaller tires.

[00115] Figures 12 and 13 shows close-ups of the reinforcing ring depicting one embodiment of the mechanical locking features. It can be seen in Figure 12 that the angle θ_A and angle θ_B formed by the circumferential facing wall surfaces of the dovetail and the circumferential direction is less than 90 degrees. Figure 13 shows a view of two adjacent reinforcing rings 500 laterally separated but aligned to allow mating of the male end 540 of a locating pin on a first reinforcing ring with the female end 550 of a locating pin on a second reinforcing ring.

[00116] Figure 14 shows a mold surface 600 of an injection mold into which the reinforcing ring may be placed. Pin 530 may be configured to insert into a mold recess 610. In this way, the reinforcing ring may be stabilized.

[00117] Various combinations of the above stabilization methods are meant to be included in the scope of various aspects of this invention.

[00118] Another exemplary example of a reinforcing ring 700 is shown in Figure 15. In this embodiment, the reinforcing ring 700 possesses apertures 710 which allow the annular beam forming material to pass through. Similar to the previously shown embodiments, this embodiment may have locating pins 730, 760 extending laterally or radially from the reinforcing ring.

[00119] The inventors prototyped additional midroller tires. Performance of tires with and without reinforcing rings was compared. The reinforcing ring disclosed in Figure 12 was used, with a reinforcing ring material modulus E = 7,000 MPa. The reinforcing ring material was therefore much stiffer than the elastomer material used to form the rest of the tire.

[00120] Acceptable materials for the reinforcing ring may include nylon (PA) resin with glass reinforcement of 10%, 20%, 30% or even higher. Other material choices include glass reinforced PET with glass or carbon reinforcement. Still other choices include blends of PET and PBT. Polycarbonate (PC) may be suitable with our without reinforcement.

[00121] Three tires were prototyped with the following definitions shown in Table 5 below:

[00122] Table 5. Tire embodiments characteristics.

	Elastomer modulus	Reinforcing ring?
Tire D	180 MPa	No
Tire E	180 MPa	Yes
Tire F	290 MPa	No

[00123] Figure 16 shows load vs. deflection curves for Tires D, E, and F. Tire D is the least stiff tire. The addition of the reinforcing ring in Tire E, which still using the same elastomer stiffness of Tire D, increased stiffness by about 35%. Tire F used a much stiffer elastomer, without a reinforcing ring. Tires D and F had almost the same stiffness. Therefore, the addition of a reinforcing ring enabled the use of a softer elastomer in obtaining a stiffer tire.

[00124] Softer elastomers may have enhanced material characteristics - such as, improved crack propagation resistance, lower glass transition temperature, and improved processing characteristics. Therefore, Tire E may be preferred to Tire D.

[00125] Figure 17 shows a creep displacement as a function of time for Tires D and E. In this test, the creep is a change in displacement while the tire is loaded to a static load. This simulates the condition of a vehicle that is left stationary for some period of time, during which the tire may develop a "flat" spot. Those skilled in the art of tire design realize that minimal creep displacement is a positive design attribute. A particular useful embodiment would be a tire having a reinforcing ring configured such that the creep when loaded to a design load in the radial direction over 100,000 seconds is no more than 0.6% of an initial wheel diameter.

[00126] Adding the reinforcing ring in Tire E was found to decrease creep displacement, compared to Tire D. Tire E had half the creep displacement as Tire D.

[00127] Thus, a reinforcing ring both increased vertical stiffness while improving creep performance. The ability to use a softer elastomer was also achieved.

[00128] Figure 18 is an NPT according to the invention where the annular beam further comprises a tread portion 250 disposed on the outer radial extent. The tread may be smooth or may have a tread pattern. The tread material may be any suitable material, usually of lower modulus than the elastomer used to form the annular beam and annular support. The tread material may comprise rubber, a thermo-plastic urethane (TPU), a thermoplastic vulcanized elastomer (TPV), or other suitable materials.

[00129] Selected combinations of aspects of the disclosed technology correspond to a plurality of different embodiments of the present invention. It should be noted that each of the exemplary embodiments presented and discussed herein should not insinuate limitations of the present subject matter. Features or steps illustrated or described as part of one embodiment may be used in combination with aspects of another embodiment to yield

yet further embodiments. Additionally, certain features may be interchanged with similar devices or features not expressly mentioned which perform the same or similar function.

[00130] The terms "a," "an," and the singular forms of words shall be taken to include the plural form of the same words, such that the terms mean that one or more of something is provided. The terms "at least one" and "one or more" are used interchangeably. Ranges that are described as being "between a and b" are inclusive of the values for "a" and "b."

[00131] The citation of any document is not an admission that it is prior art with respect to any invention disclosed or claimed herein or that it alone, or in any combination with any other reference or references, teaches, suggests or discloses any such invention. Further, to the extent that any meaning or definition of a term in this document conflicts with any meaning or definition of the same term in a document incorporated by reference, the meaning or definition assigned to that term in this document shall govern.

WHAT IS CLAIMED IS:

1. A track system for a vehicle comprising:
   a plurality of track contacting wheels, wherein at least one of said plurality of track contacting wheels is a non-pneumatic tire;
   the non-pneumatic tire comprising:
      an annular beam; and
      an annular support extending radially inward from the annular beam, the annular support being configured to develop tension forces when the non-pneumatic tire is loaded to the design load;
   the track system further comprising a track; and
   a dual tension system for the track.
2. The track system of claim 1 wherein the annular support comprises plurality of spokes.
3. The track system of claim 2 wherein each spoke of the plurality of spokes do not intersect other ones of the spokes.
4. The track system of claim 2 or 3 wherein each spoke extends from the first lateral side to the second lateral side.
5. The track system of any one of the above claims wherein the annular beam possesses a plurality of openings.
6. The track system of claim 6 wherein the plurality of openings extend from the first lateral side to the second lateral side.
7. The track system of any one of the above claims wherein the non-pneumatic tire is comprised of an elastomeric material having a modulus greater than 180 MPa and less than 1600 MPa.
8. The track system of any one of the above claims wherein the tension forces are developed in the annular support away from the contact patch when the nonpneumatic tire is loaded to the design load.
9. The track system of any one of the above claims wherein the dual tension system for the track is configured to control a tension of the track and comprises:
   a first tensioner including a resilient element configured to exert a force on a front one of the track-contacting wheels; and

a second tensioner including a resilient element spaced from the resilient element of the first tensioner in a longitudinal direction of the track system and configured to exert a force on a rear one of the track-contacting wheels.

10. The track system of claim 10 wherein the resilient element of the first tensioner is a spring.

11. The track system of claim 11 wherein the resilient element of the second tensioner is a spring.

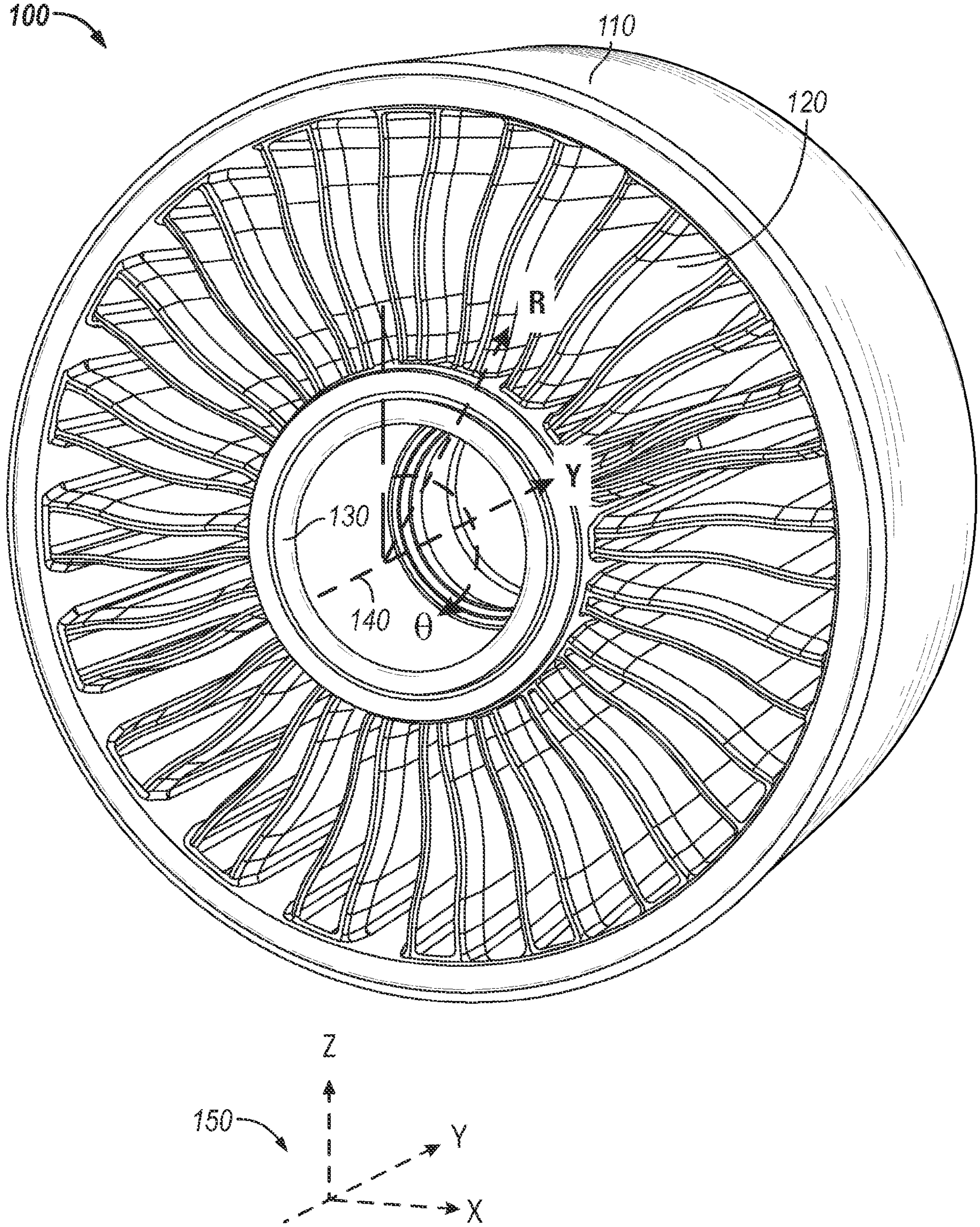


FIG. 1

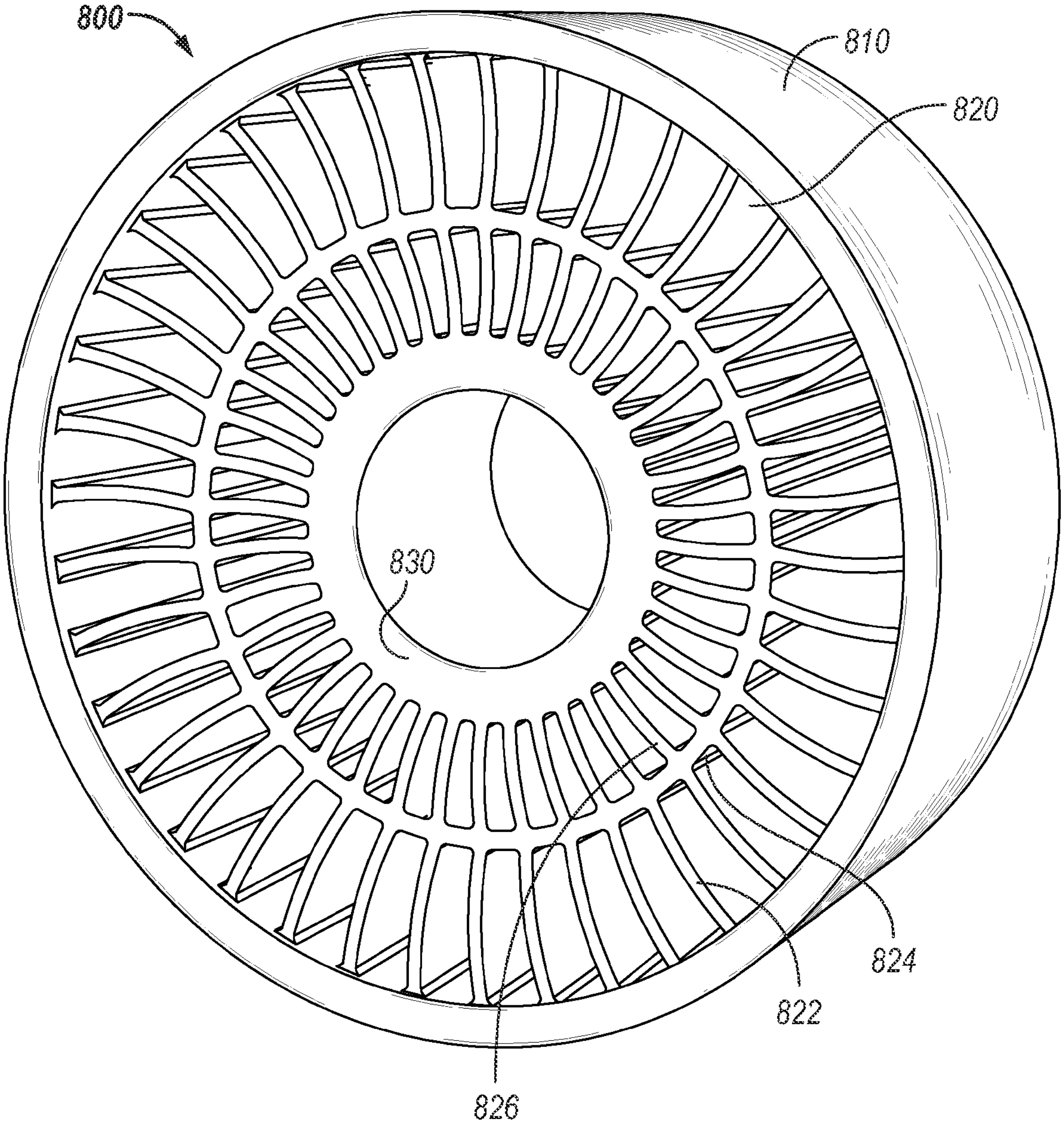


FIG. 2

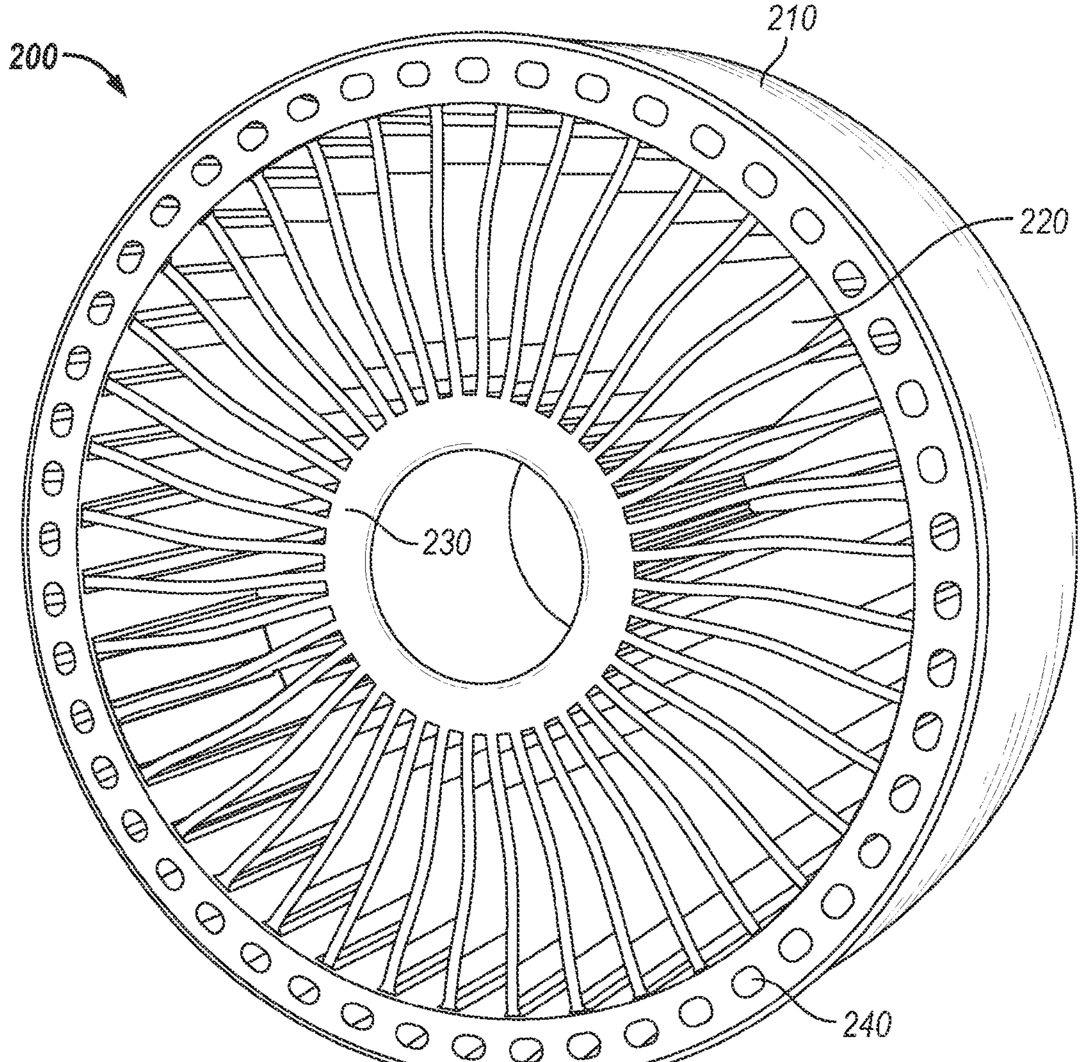


FIG. 3

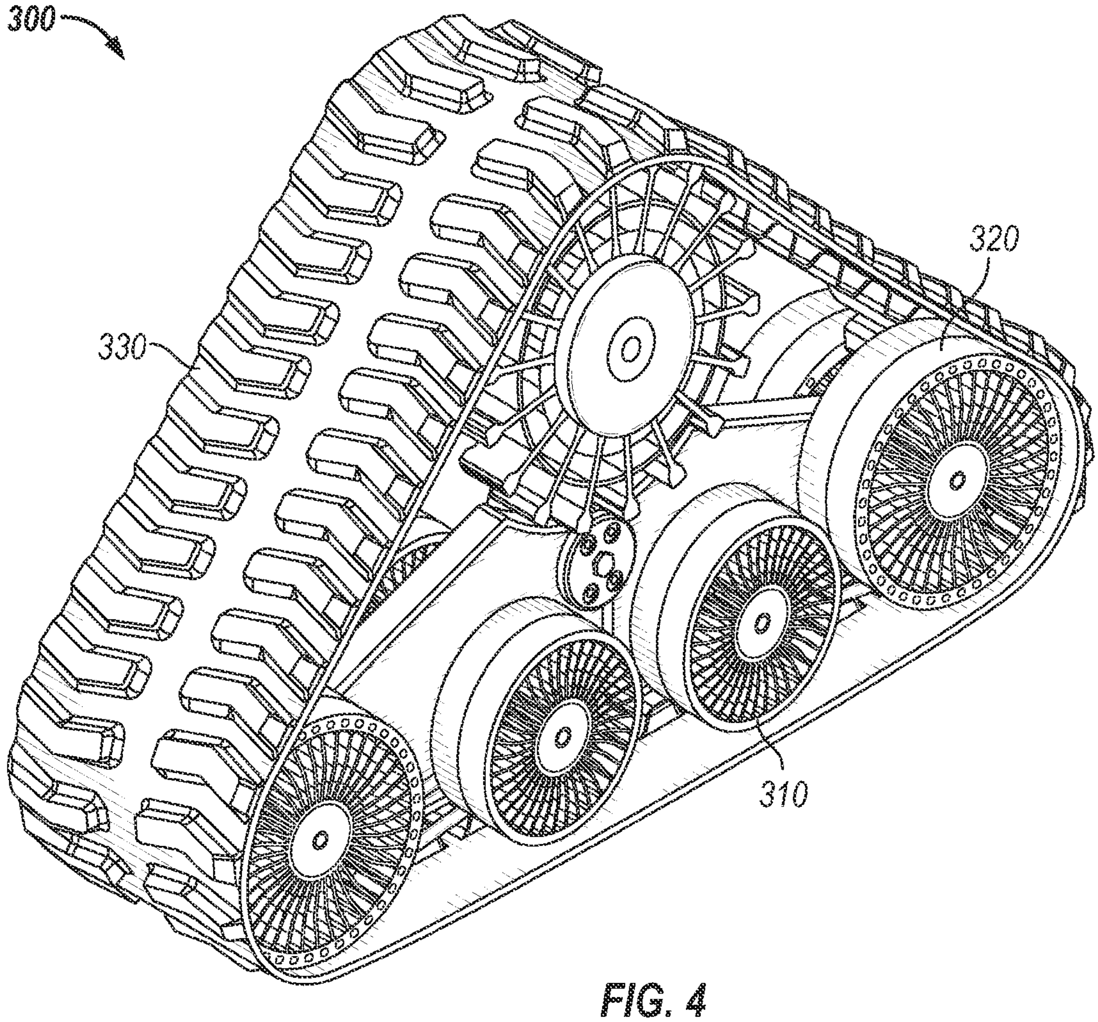


FIG. 4

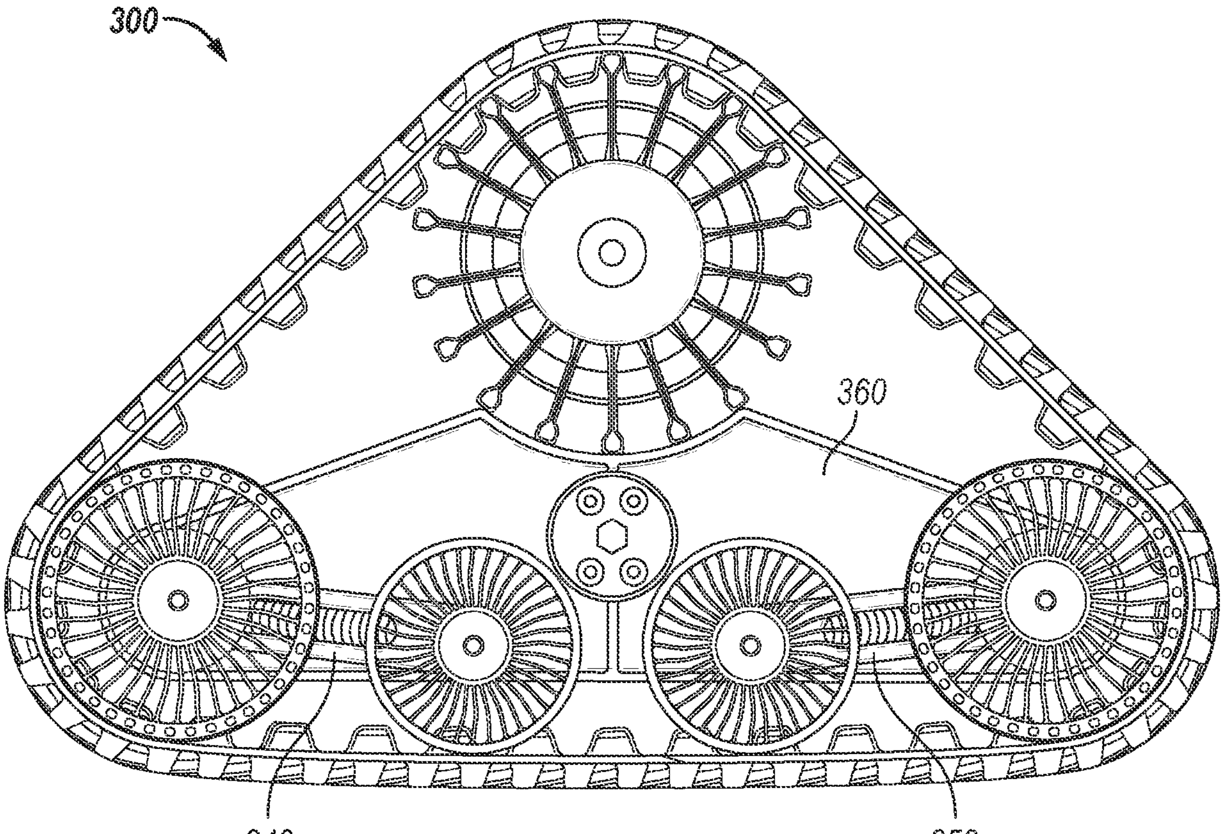
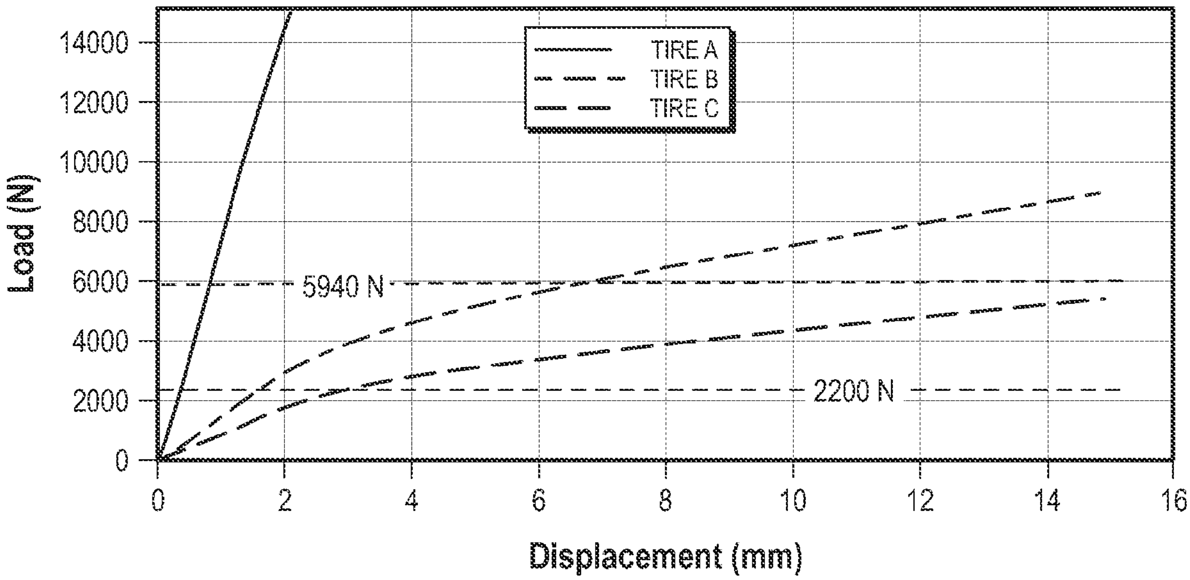
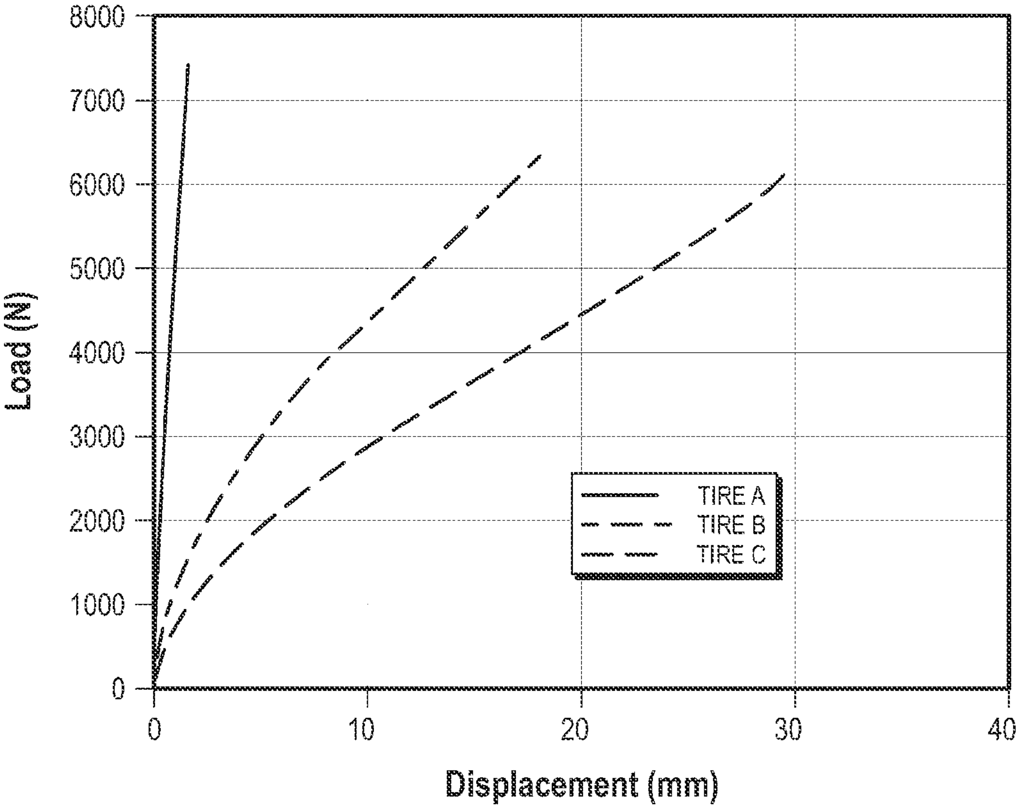


FIG. 5



TIRE A
TIRE B
TIRE C
14000
12000
10000
8000
6000
4000
2000
0
Load (N)
5940 N
2200 N
0
2
4
6
8
10
12
14
16
Displacement (mm)

FIG. 6



8000
7000
6000
5000
4000
3000
2000
1000
0
Load (N)
TIRE A
TIRE B
TIRE C
0
10
20
30
40
Displacement (mm)

FIG. 7

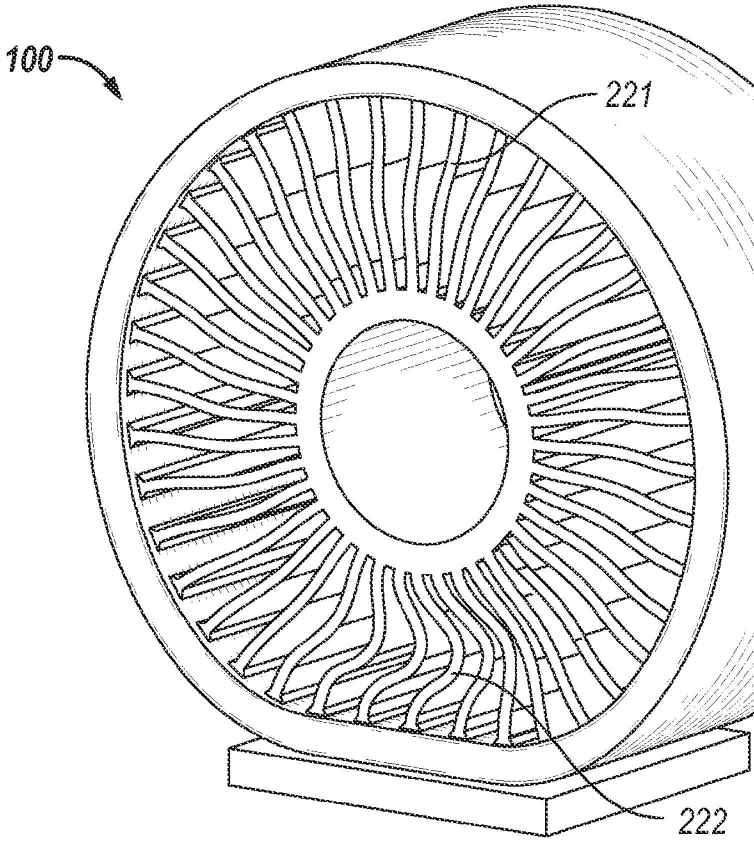


FIG. 8

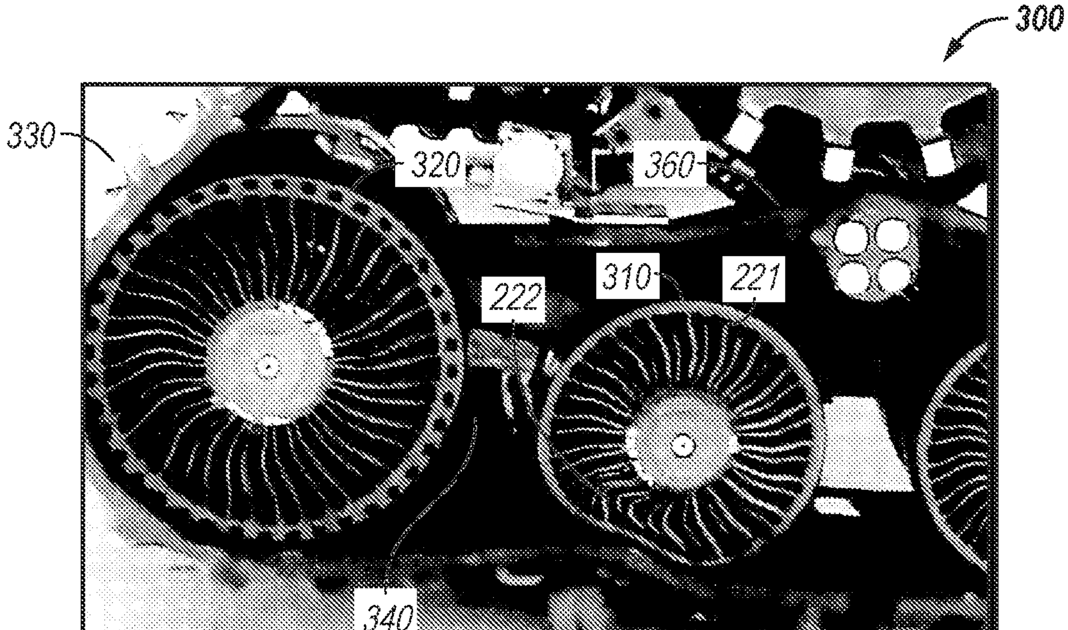


FIG. 9

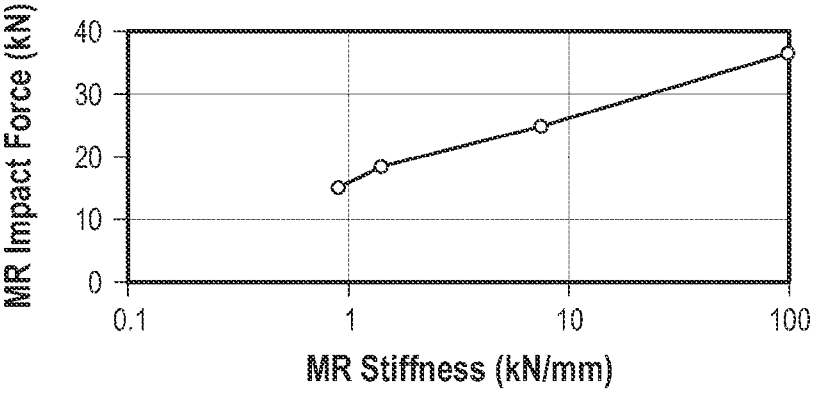

MR Impact Force (kN)
40
30
20
10
0
0.1
1
10
100
MR Stiffness (kN/mm)

FIG. 10

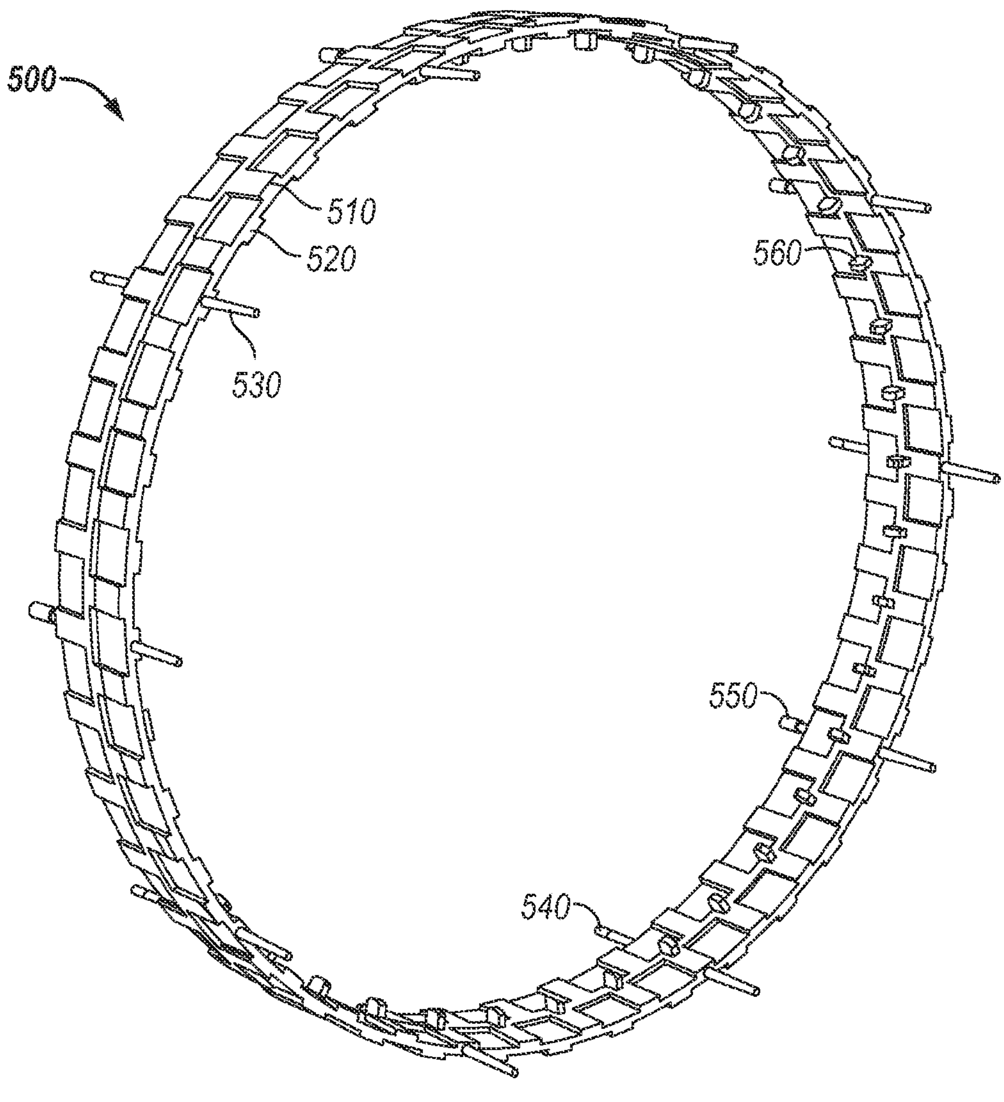

500
510
520
530
560
550
540

FIG. 11

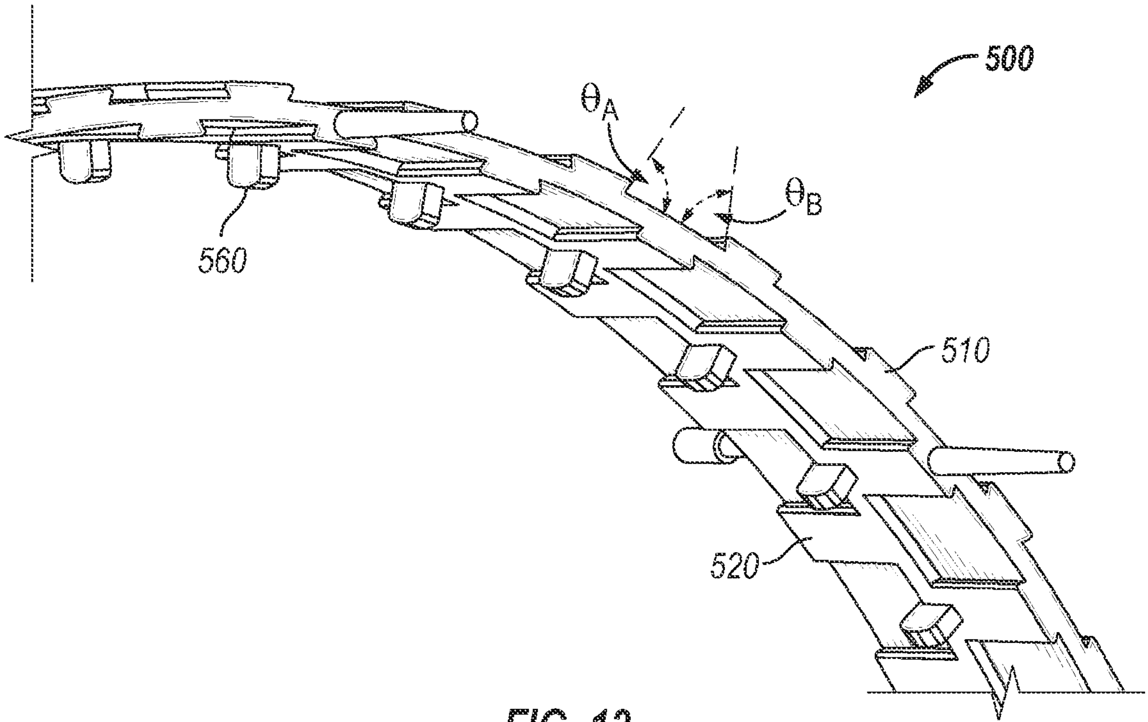


FIG. 12

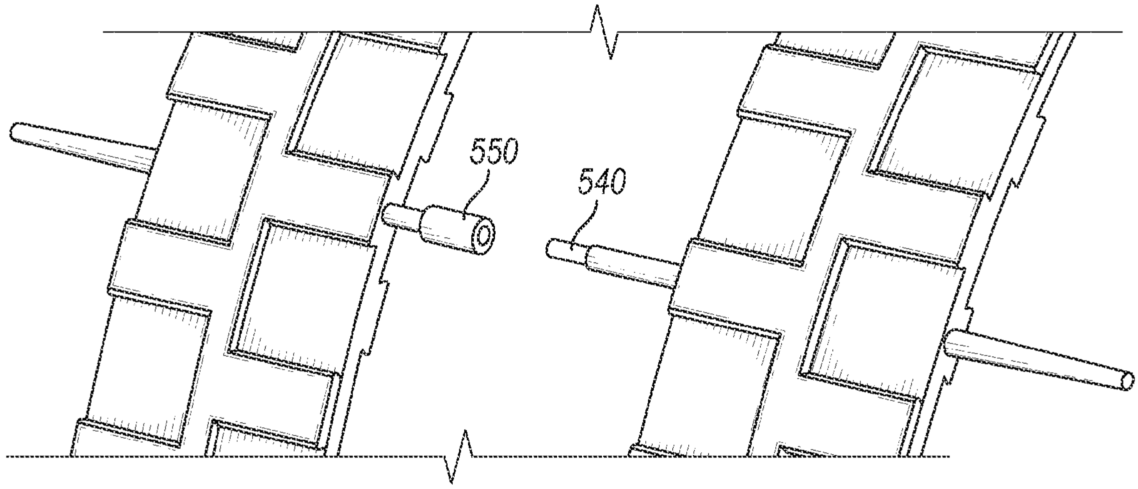


FIG. 13

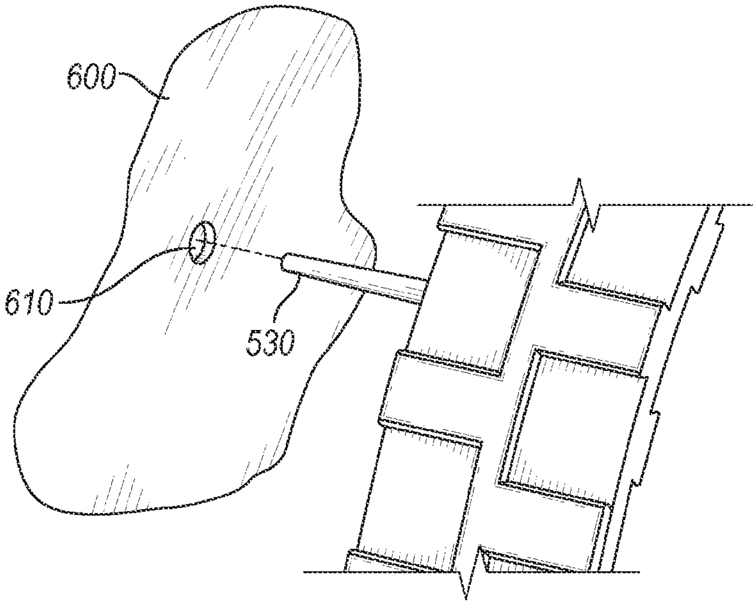


FIG. 14

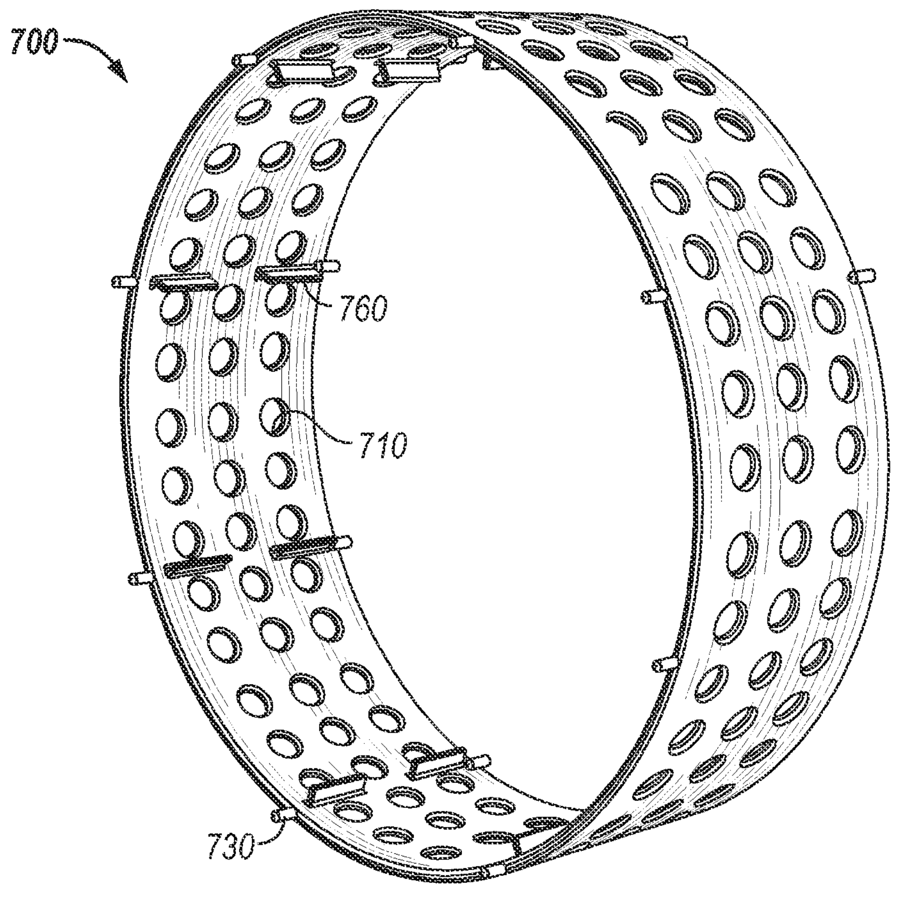


FIG. 15

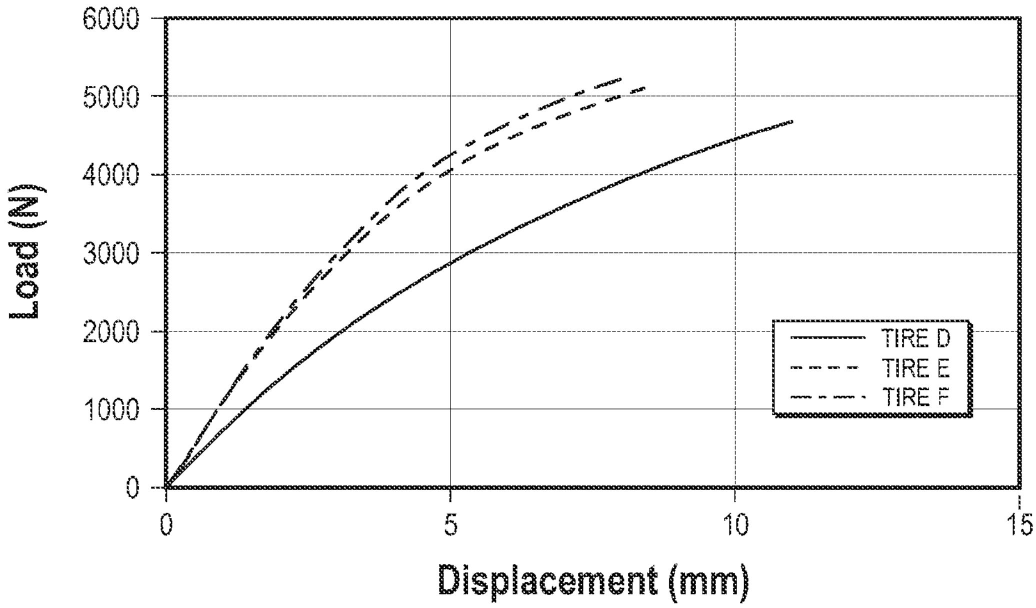

6000
5000
4000
3000
2000
1000
0
Load (N)
0
5
10
15
Displacement (mm)
TIRE D
TIRE E
TIRE F

FIG. 15

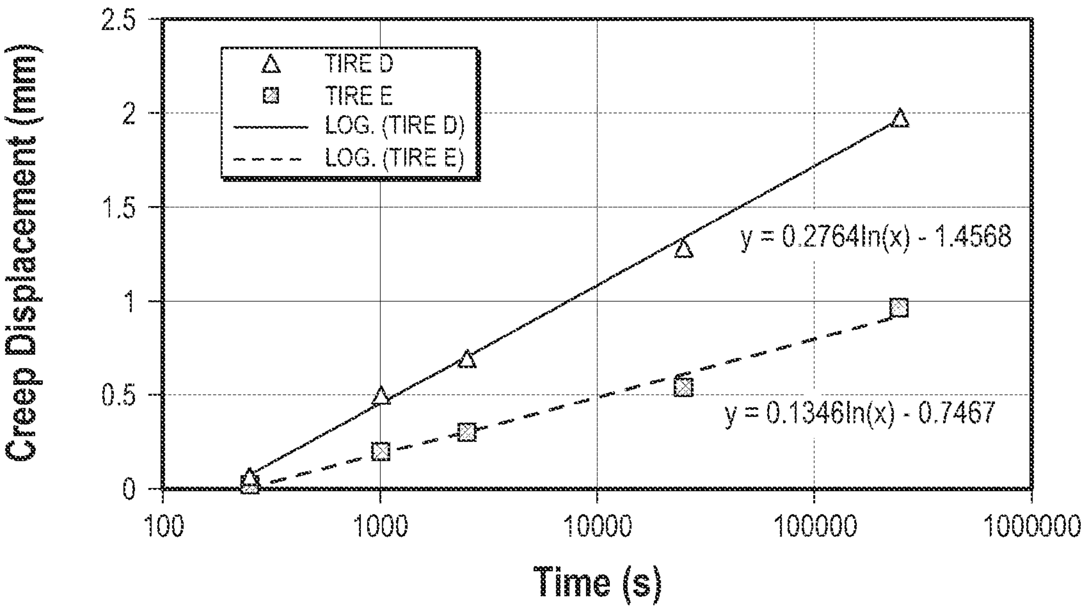

2.5
2
1.5
1
0.5
0
Creep Displacement (mm)
100
1000
10000
100000
1000000
Time (s)
TIRE D
TIRE E
LOG. (TIRE D)
LOG. (TIRE E)
y = 0.2764ln(x) - 1.4568
y = 0.1346ln(x) - 0.7467

FIG. 16

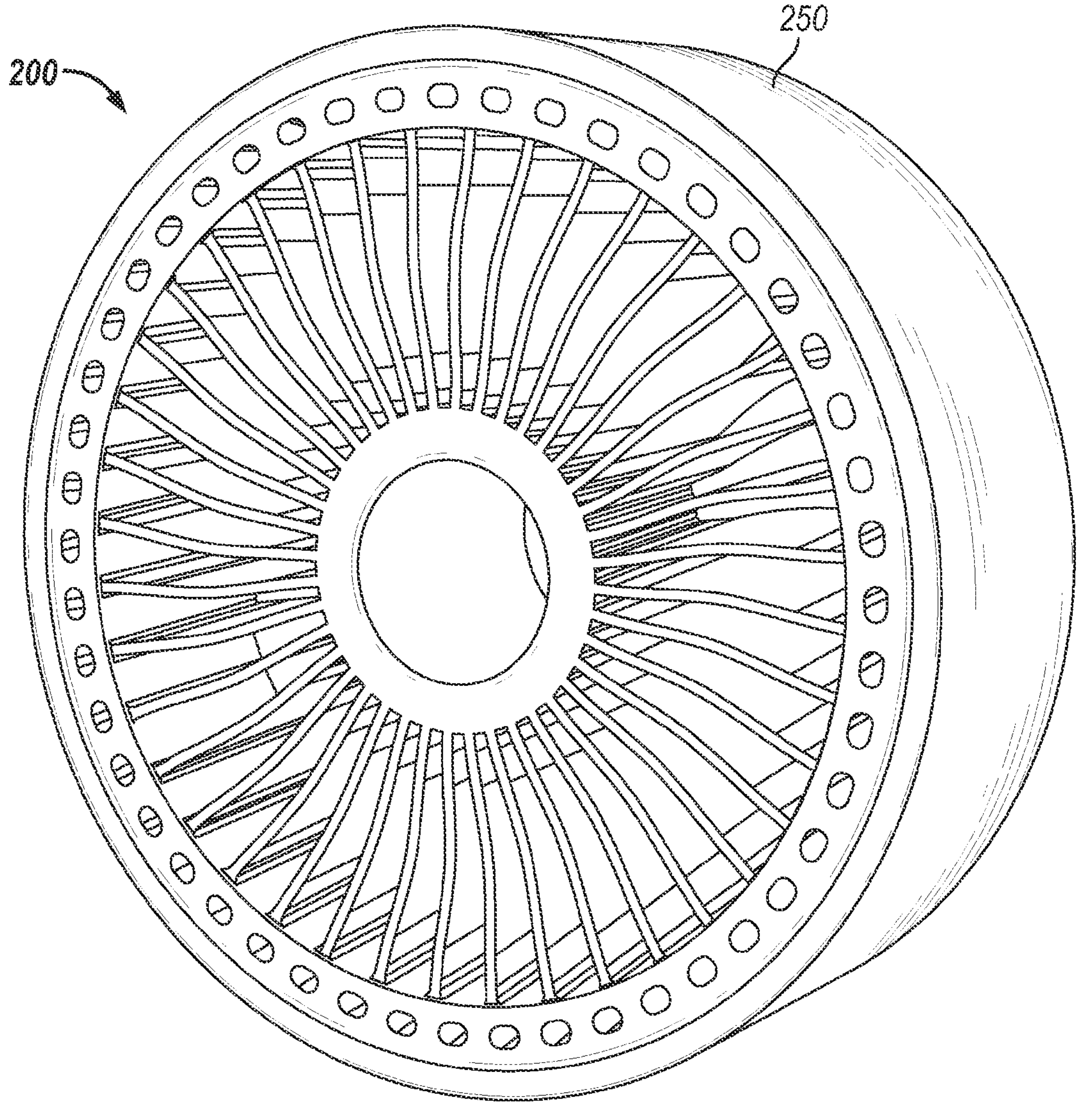


FIG. 18

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2024/030229

A. CLASSIFICATION OF SUBJECT MATTER
INV. B62D55/14 B60C7/14 B62D55/30
ADD.

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)
B62D 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 practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2020/277012 A1 (THOMPSON RONALD H [US] ET AL) 3 September 2020 (2020-09-03) cited in the application paragraphs [0057] - [0089] figures 1A,4-8 figures 14-18 -----	1-8
A	WO 2022/104481 A1 (CAMSO INC [CA]) 27 May 2022 (2022-05-27) cited in the application column 5, lines 1-27 figures 1,2,8 -----	1,9-11
A	EP 3 957 491 A1 (KAESSBOHRER GELAENDEFAHRZEUG AG [DE]) 23 February 2022 (2022-02-23) paragraphs [0012] - [0019] figures 1-2 -----	1,9
	-/--	

[X] Further documents are listed in the continuation of Box C.   [X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"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
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 September 2024	09/10/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Ionescu, Bogdan

1

International application No
PCT/US2024/030229

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 3 153 383 A2 (POLARIS INC [US]) 12 April 2017 (2017-04-12) paragraphs [0012] - [0016] paragraphs [0031] - [0032] figures 1-4 -----	1

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2024/030229

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