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(54) AVOIDANCE OF RESONANCE IN THE INFLATABLE SPORT BALL BY LIMITING THE CRITICAL RATIO

(76) Inventors: **Thomas A. Veilleux**, Charlton, MA (US); **Ronald P. LaLiberty**, Dudley, MA (US)

Correspondence Address:
THOMAS, KAYDEN, HORSTEMEYER & RISLEY, LLP
100 GALLERIA PARKWAY, NW
STE 1750
ATLANTA, GA 30339-5948 (US)

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(60) Provisional application No. 60/252,443, filed on Nov. 21, 2000. Provisional application No. 60/159,311, filed on Oct. 14, 1999.

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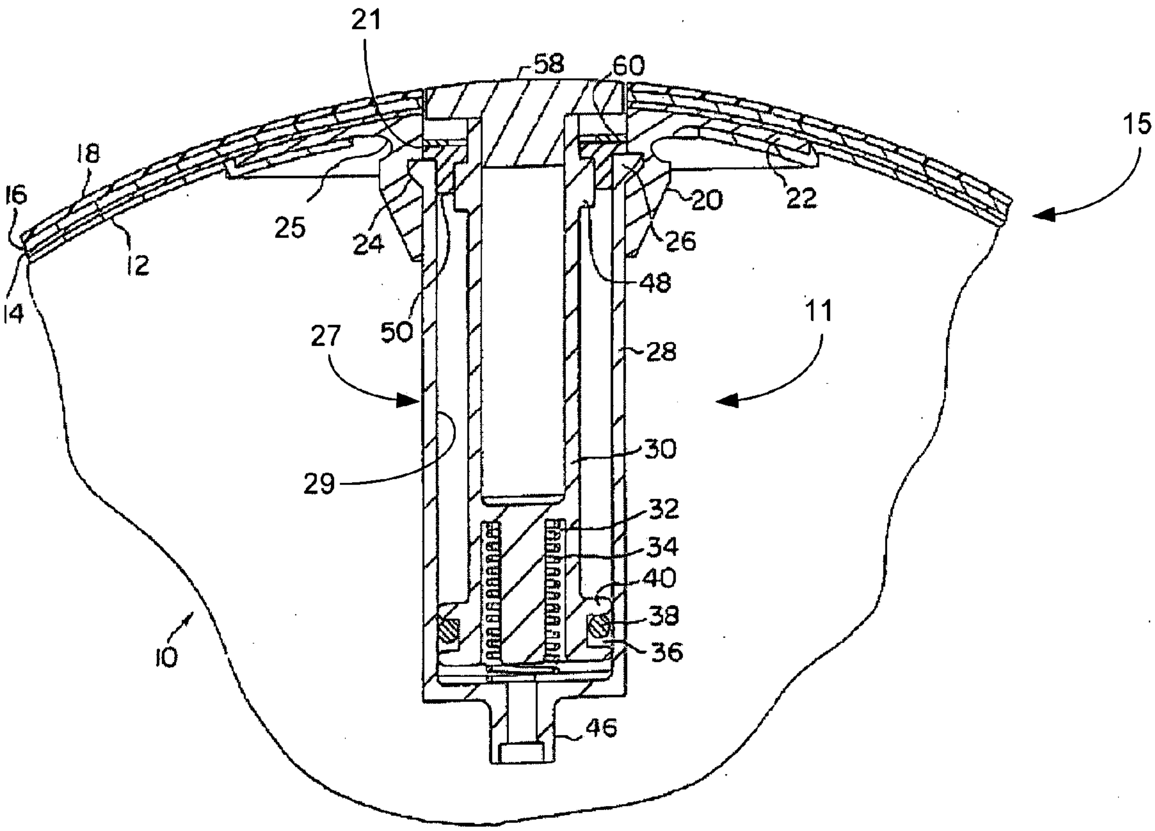
(57) **ABSTRACT**

A sport ball having an internal device such as an internal pump has a critical ratio that insures that rebound characteristics or coefficient of restitution of the ball, such as a basketball, will be acceptable for use. The invention also includes the method for evaluating design and/or quality control of a sport ball by measuring the internal vibration and determining the critical ratio of the sport ball.



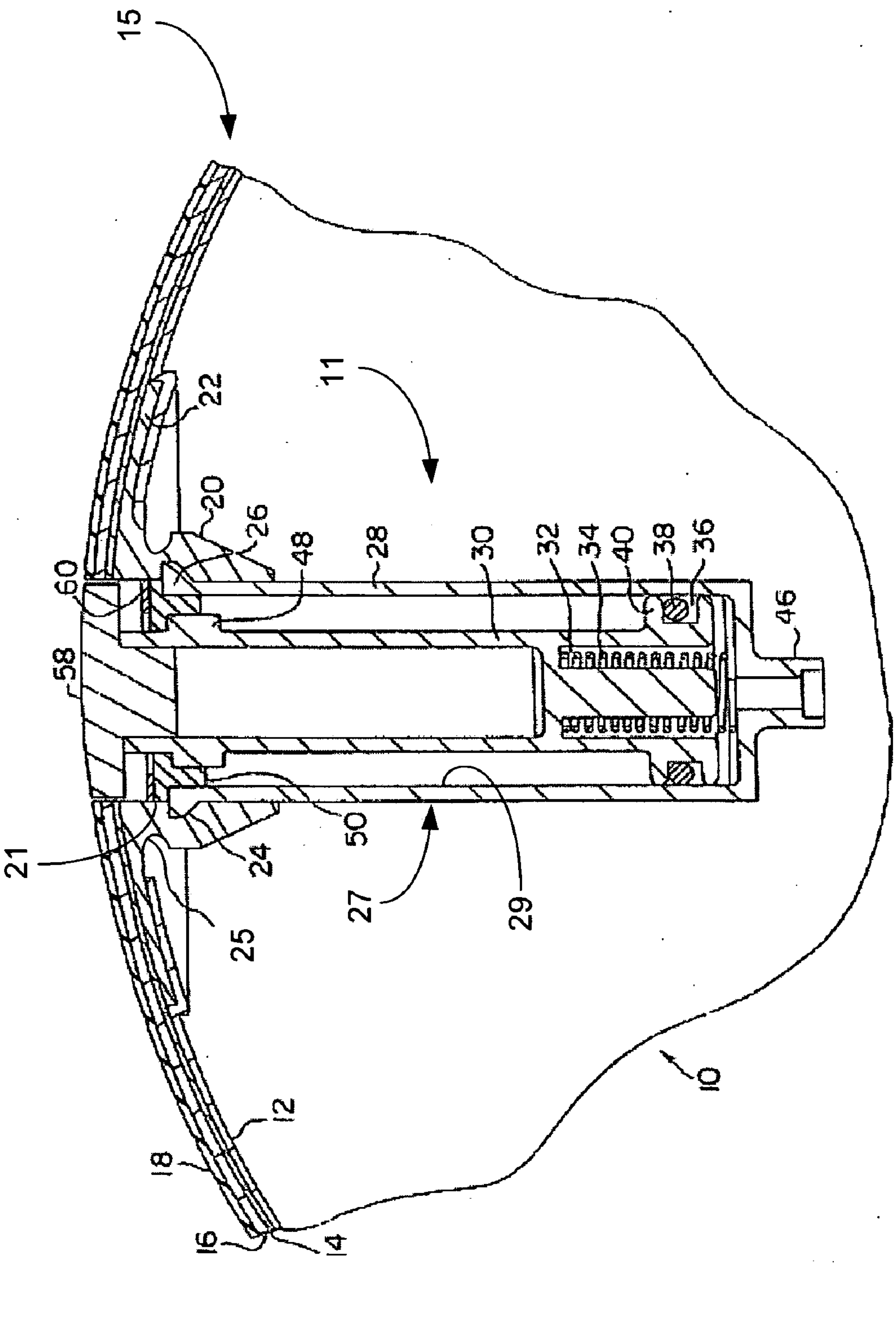

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FIG. 1

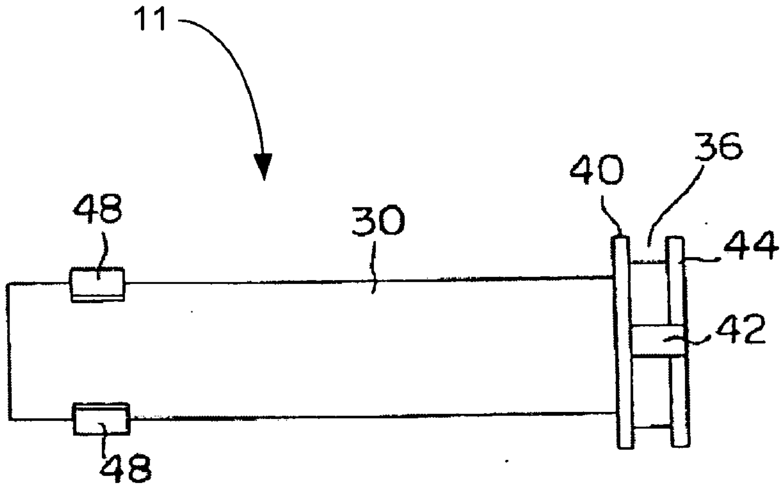

FIG. 2

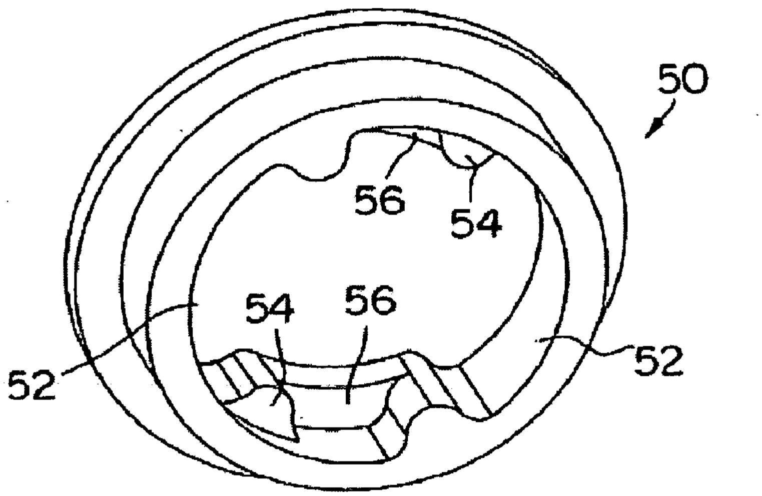

FIG. 3

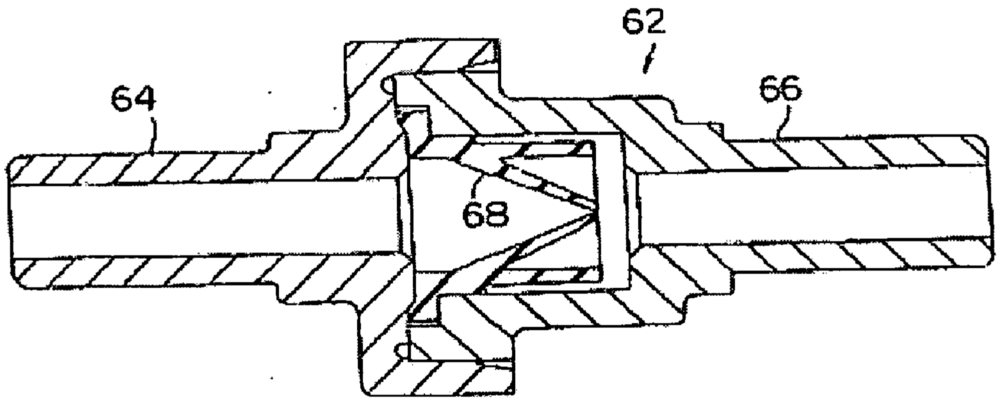

FIG. 4

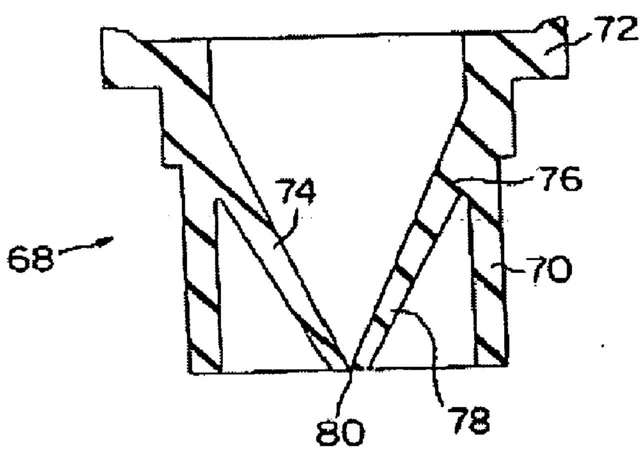

FIG. 5

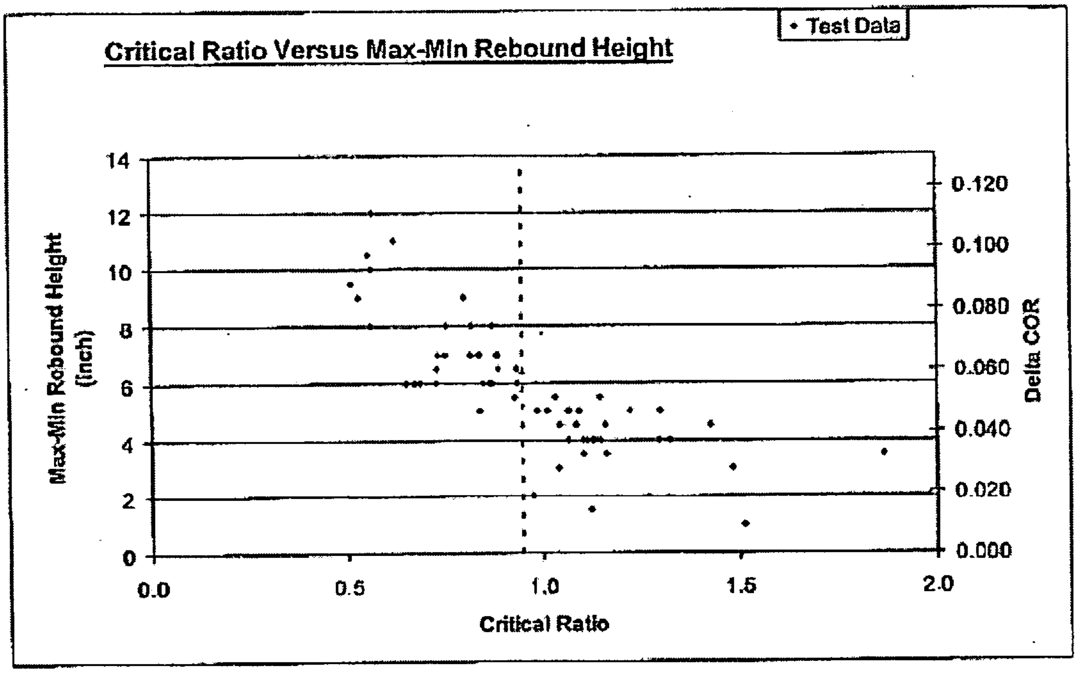
Critical Ratio Versus Max-Min Rebound Height
Test Data
Max-Min Rebound Height (inch)
Delta COR
Critical Ratio
14
12
10
8
6
4
2
0
0.120
0.100
0.080
0.060
0.040
0.020
0.000
0.0
0.5
1.0
1.5
2.0

FIG. 6

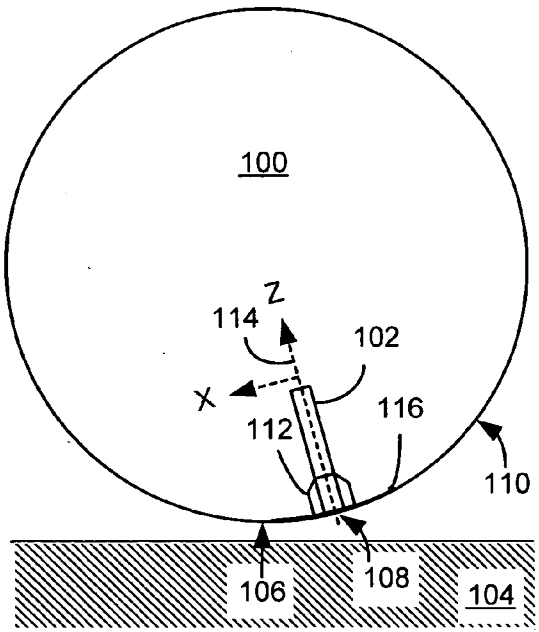
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FIG. 7A

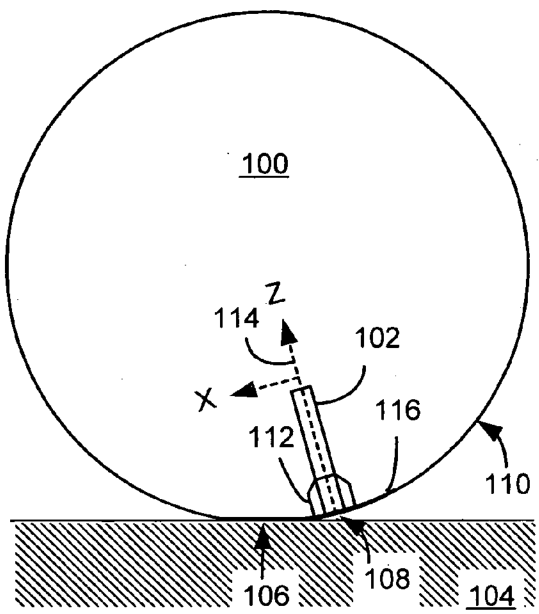
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FIG. 7B

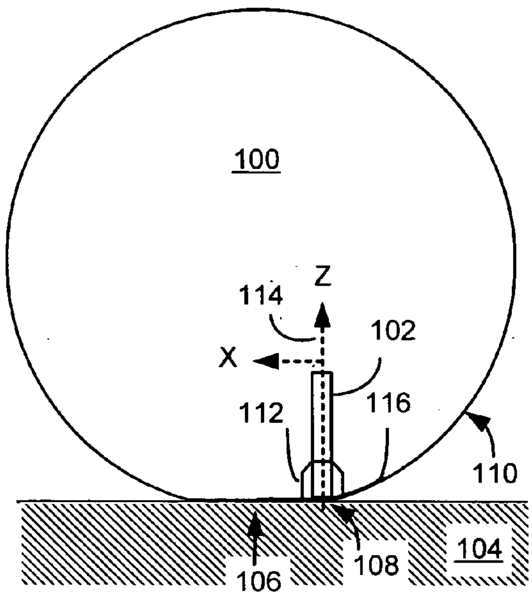

FIG. 7C

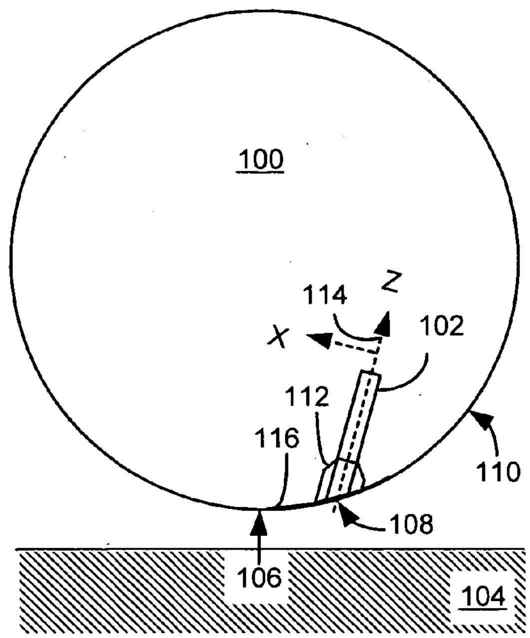

FIG. 7D

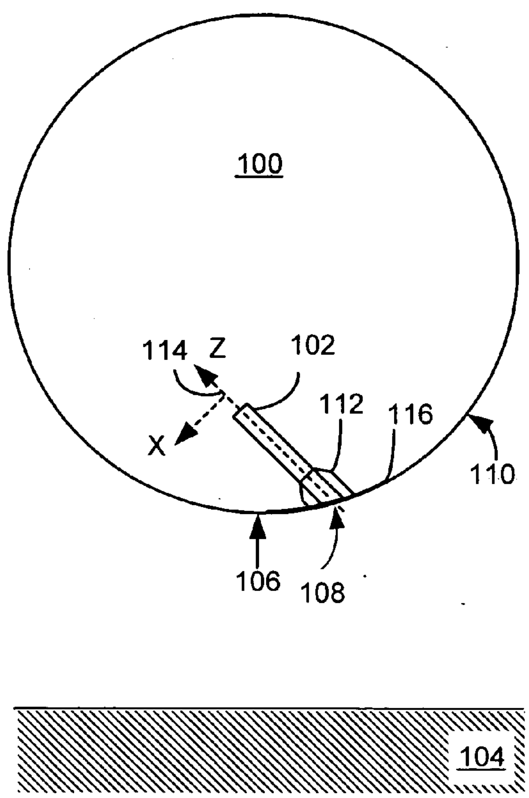

FIG. 7E

AVOIDANCE OF RESONANCE IN THE INFLATABLE SPORT BALL BY LIMITING THE CRITICAL RATIO

RELATED APPLICATIONS

[0001] This application is a Continuation-in-Part of and claims the benefit of U.S. patent application Ser. No. 09/594,980, filed Jun. 15, 2000, which is a Continuation-in-Part of and claims the benefit of U.S. patent application Ser. No. 09/478,225, filed Jan. 6, 2000, and further claims the benefit of U. S. Provisional Application No. 60/159,311, filed Oct. 14, 1999.

[0002] The applicant also claims priority based on a provisional U.S. patent application Ser. No. 60/252,443, filed Nov. 21, 2000 entitled "Avoidance of Resonance in the Inflatable Sport Ball by Limiting the Critical Ratio."

FIELD OF THE INVENTION

[0003] The present invention relates generally to a hollow sport or game ball having a device extending into ball, and more specifically to the natural frequency of vibration of the device.

BACKGROUND OF THE INVENTION

[0004] A conventional inflatable sports ball having an inflation valve is generally constructed such that the inflation valve does not adversely effect the performance characteristics of the ball. For example, when a conventional basketball is bounced on its valve, the conventional basketball rebounds within predetermined parameters, and the rebound characteristics are substantially the same for the ball as a whole. In other words, there should be very little difference in the rebound characteristics of a conventional basketball regardless of whether it is dropped on its valve or any other part of the basketball.

[0005] Internal vibration in a sport ball may adversely affect the performance of the sport ball. For example, a basketball with vibration problems may not dribble or bounce consistently, and a soccer ball may roll or travel inconsistently towards or away from the intended target when kicked or thrown. If the sport ball is a sport ball with a self contained inflation mechanism, such as a pump, or other internal device, there is an increased potential for vibration problems due to the added internal device. One of the worst internal vibration problems is a condition called resonance. Resonance, as used herein, is when the impact loading of an object, such as a ball, occurs in tune with the object's natural frequency of vibration. The natural frequency of the ball is the frequency that the ball oscillates at in the absence of external forces.

[0006] Conventional inflatable sport balls, such as basketball, footballs, soccer balls, volleyballs and playground balls, are inflated through a traditional inflation valve using a separate inflation needle that is inserted into a self-sealing inflation valve. A separate pump, such as a traditional bicycle pump, is connected to the inflation needle and the ball is inflated using the pump. The inflation needle is then withdrawn from the inflation valve that self-seals to maintain the pressure. This system works fine until the sport ball needs inflation or a pressure increase and a needle and/or pump are not readily available.

[0007] Thus, what is sought, among other things, is a sports ball having a self-contained internal device for inflating the sports ball, wherein the self-contained internal device does not adversely effect performance characteristics.

[0008] Furthermore, what is sought is a method to measure the natural vibrations of internal devices and control the vibrational energy of the internal devices so that the consumer does not notice the vibration of the internal device in a final product.

SUMMARY OF THE INVENTION

[0009] Embodiments of the present invention provide a sports ball having an internal device that conforms to predetermined performance-characteristics and method for testing the performance characteristics of the sports ball.

[0010] An embodiment, among others, of a sports ball of the present invention includes a ball that has a carcass having at least one layer of material. The carcass defines an exterior surface and a generally hollow interior, and a device having an top and a bottom, wherein the device extends into the generally hollow interior of the carcass. The sports ball also includes a housing having an upper end with flange extending therefrom and a lower end. The housing defines a central opening extending between the upper end and lower end of the housing. The device is received by the central opening of the housing and extends therefrom, the flange is coupled to the at least one layer of material, and the lower end is disposed within the hollow interior of the carcass. The natural frequency of oscillation of the housing with the device coupled thereto is not in resonance with a predetermined loading force such that the performance characteristics of the ball are within an allowable range from specified performance characteristics. The specified performance characteristics are for a second ball that does not include a second device and a second housing.

[0011] The present invention can also be viewed as providing methods for testing a hollow ball. In this regard, one embodiment of such a method, among others, can be broadly summarized by the following steps: providing a carcass and providing a device. The carcass defines an exterior surface and a generally hollow interior, and the carcass includes at least one layer of material. The steps also including coupling the device to the at least one layer of material, wherein the device extends generally inward from the one layer of material and is substantially disposed into the generally hollow interior; providing a loading force that deforms at least a portion of the ball; and determining whether the device oscillates at a frequency that is in resonance with the loading force.

[0012] Other systems, methods, features, and advantages of the present invention will be or become apparent to one with skill in the art upon examination of the following drawings and detailed description. It is intended that all such additional systems, methods, features, and advantages be included within this description, be within the scope of the present invention, and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWING

[0013] The invention will be better understood by reference to the accompanying drawings in which:

[0014] **FIG. 1** shows a cross section of a portion of a sport ball with a self-contained piston and cylinder arrangement operable from outside the ball for adding air pressure to the ball.

[0015] **FIG. 2** is a side view of the pump shown in **FIG. 1**.

[0016] **FIG. 3** is an isometric view of the cap for the pump of **FIG. 1** showing the configuration for locking and unlocking the pump piston.

[0017] **FIG. 4** is a detailed cross-section view of a one-way valve assembly for use on the exit of the pump of **FIG. 1**.

[0018] **FIG. 5** is a more detailed view of the duckbill valve in the **FIG. 4** assembly.

[0019] **FIG. 6** is a diagrammatic view showing the critical ratio versus maximum minus minimum rebound height for various basketball designs.

[0020] **FIGS. 7A-7E** represent dynamic deformation of a virtual basketball having an internal device such as a pump.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0021] The present invention relates to all balls that contain internal devices or components within a ball that may have an adverse effect on the characteristics of the ball. For example, a pump mechanism for inflating or adding pressure to a ball or other devices that are internal to a ball may affect the performance characteristics of the ball. Examples of internal devices, referred to herein as components, which may be self-contained in the sport balls include, but are not limited to, a pump mechanism for inflating or adding pressure to a ball, a storage container, a flashlight, a key holder, a watch, a pressure relief valve, a beeper, pressure gauges, temperature gauges, and the like. In some cases, such balls have an inherent asymmetric construction. Even if a counterweight is positioned at a directly opposite portion of the ball from the pump mechanism or other component, the ball assembly is still asymmetric when considered from other axes. Examples of sport balls which-may-be-affected include, but are not limited to, any inflatable sport ball such as a basketball, volleyball, soccer ball, football, playground ball, rugby ball, tennis ball, racquet ball, squash ball, or other inflated ball.

[0022] In a preferred embodiment, the sport ball is an inflated sport ball with a self contained inflation mechanism or other internal device. The interior of the sport ball may also be hollow or may contain a foamed material. The sport ball may be any sport ball, such as, but not limited to, a basketball, a football, a soccer ball, a volleyball, or a playground ball.

[0023] Methods of characterizing the rebound characteristics of a ball include, but are not limited to, coefficient of restitution (COR), rebound height, rebound consistency, and critical ratio. For example, a basketball comprising a self-contained inflation mechanism according to the invention preferably has a coefficient of restitution range of 0.750-0.813 when tested repeatedly at different ball orientations, combined with a difference between the maximum and minimum coefficient of restitution values of 0.051 or less. In another preferred form of the invention, the difference between the maximum and minimum coefficient of restitution values is 0.036 or less. When described by rebound height, a basketball of the invention has a rebound height of 50-57 inches when dropped l0 on a wooden floor from a height of 72 inches. The difference between the maximum and minimum rebound heights when the ball is dropped repeatedly with different orientations is 5.5 inches or less and more preferably 4 inches or less. In another preferred form of the invention, the basketball has a rebound height of 50-54 inches when dropped on a wooden floor from a height of 72 inches.

[0024] In a preferred embodiment, a sport ball having an internal device has a critical ratio, which is defined hereinbelow, and the critical ratio of the sport ball is greater than or equal to a predetermined minimum acceptable value. A sport ball whose critical ratio is equal to or greater than the acceptable minimum critical ratio will have performance characteristics that substantially match a similar sport ball that does not include a similar internal device. For example, a first basketball whose critical ratio is equal to or greater than the acceptable minimum will have performance characteristics that substantially match the performance characteristics of a second conventional basketball, i.e., a basketball that does not include a similar internal device. The critical ratio is defined as the half period of vibration of the device divided by the duration of the ball's impact with the floor, i.e., the duration of a loading force. Preferably, the critical ratio is 0.95 or greater. Generally, sport balls such as, but not limited to, basketballs, volleyballs, foot balls, etc., need to meet certain performance characteristics, which are normally set by a regulatory body such as the National Football League or National Collegate Athletic Association etc., and in preferred embodiments of the invention, the sports balls having internal devices are designed such that their performance characteristics conform to predetermined standards.

[0025] Embodiments of the present invention are described in terms of a basketball having an internal device mounted therein. The internal device is described in terms of a self-contained pump, but this is for purposes of clarity and is provided as a non-limiting example. The internal device has various degrees of freedom including oscillatory (swinging) modes such that the internal device can swing about the region where it is coupled to the ball. As will be described in detail hereinbelow, the natural mode of vibration of the internal device can cause the ball having the internal device to exhibit characteristics that are atypical and unacceptable for such sports balls. For example, the rebound characteristics of a basketball may be affected to such a degree that this characteristic is no longer within standard rebound range.

[0026] For the purposes of this disclosure, the natural mode of vibration of the internal device is the mode at which the internal device swings about the region from which it is coupled to the ball and is generally the lowest vibrational mode. Normally, a sport ball having an internal component exhibits its worst deviation from standard performance characteristics when the vibrational energy of the internal device is high and when the natural mode of vibration is in resonance with a loading force.

[0027] The invention will be better understood by first considering the structure of a typical ball incorporating one embodiment of an internal device. Referring to **FIGS. 1 and 2** of the drawings, **FIG. 1** is a partial cut away of a sport ball **10** having an internal device **11**, and **FIG. 2** illustrates an embodiment in which the internal device **11** is a self-contained inflation device, hereinafter "pump." The ball **10** is similar to a typical basketball, the construction of which includes a carcass **15** having a rubber bladder **12** for air retention, a layer **14** composed of layers of nylon or polyester yarn windings wrapped around the bladder **12** and an outer rubber layer **16**. For a laminated ball, an additional outer layer **18** of leather or a synthetic material comprises panels that are applied by adhesive and set by cold molding, or other process known in the art for adhering panels to the ball. The yarn windings are preferably randomly oriented and two or three layers thick. The yarn windings form a layer which cannot be expanded to any significant degree and which restricts the ball from expanding to any significant extent above its regulation size when inflated above its normal playing pressure. For footballs, volleyballs and soccer balls, etc., this yarn layer is referred to as a lining layer and is usually composed of cotton or polyester cloth that is impregnated with a flexible binder resin such as vinyl or latex rubber.

[0028] Incorporated into the carcass of the ball of the invention during the formation is a rubber pump boot or housing **20** with a central opening **21** and with a flange **22** which is bonded to the bladder using a rubber adhesive. The flange **22** extends between the rubber bladder **12** and the layer of windings **14**. An aluminum molded plug (not shown) is inserted into the central opening **21** of the housing **20** during the molding and winding process so that the central opening **21** of the housing **20** maintains its proper shape and so that the bladder **12** can be inflated during the manufacturing process. The central opening **21** through the housing **20** in configured with a groove **24** to hold a flange **26** on the upper end of the pump cylinder **28**. The cylinder can optionally be bonded to the housing **20** using any suitable flexible adhesive (epoxy, urethane or other.) The housing **20** has a groove **25**, which contributes to the bounce consistency of the ball.

[0029] **FIGS. 2 through 6** of the drawings relate to a specific embodiment of a self-contained inflation pump. A self-contained inflation pump **27** includes a pump cylinder **28** and a pump piston **30**. The piston cylinder **28** defines an inner wall **29**, and located in the pump cylinder **28** is the pump piston **30**, which is shown in **FIGS. 1 and 2**. The piston includes an annular groove **32** at the bottom end, which contains the spring **34** which biases the piston upwardly in the cylinder **28**. Also, at the bottom end of the piston **30** is a circumferential O-ring groove **36** containing an O-ring **38**. The O-ring groove **36** is defined by an upper flange **40** and a lower flange **44** that extend approximately radially outward toward the inner wall **29**.

[0030] As seen in **FIG. 2**, the O-ring groove **36** is dimensioned such that the O-ring **38** can move up and down in-the groove **36**. The O-ring is in the position shown in **FIG. 1** when the piston is pushed down. In this position, the O-ring seals between the cylinder wall and the upper flange **40** of the groove **36**. When the piston **30** is forced up by the spring **34**, the O-ring **38** moves,.relative to the piston **30**, to the bottom of the groove **36**. With the O-ring **38** at the bottom of groove **36**, a recess **42** is opened thereby allowing air to enter the cylinder **28** below the piston **30**. Then, when the piston is pushed down, the O-ring moves, relative to the piston, back up to the top of the groove and seals to force the air out through a cylinder exit nozzle **46**.

[0031] At the upper end of the piston are the two flanges **48** which cooperate with a cylinder cap **50** to hold the piston down in the cylinder and to release the piston for pumping. The cylinder cap **50** is fixed into the top of the cylinder **28** and the piston **30** extends through the center of the cylinder cap **50**. The cap **50** is cemented into the cylinder **28**. **FIG. 3** shows an isometric view of the bottom of the cylinder cap **50** and illustrates the open areas **52** on opposite sides of the central opening through which the two flanges **48** on the piston can pass in the unlocked position. In the locked position, the piston is pushed down and rotated such that the two flanges **48** pass under the projections **54** and are rotated into the locking recesses **56**. Attached to the upper end of the piston **30** is a button or cap **58** that is designed to essentially completely fill the hole in the carcass and to be flush with the surface of the ball. This button may be of any desired material such as cast urethane or rubber. Mounted on the upper surface of the cylinder cap **50** is pad **60** which is engaged by the button **58** when the piston is pushed down against the spring force to lock or unlock the piston. The pad provides cushioning to the pump and should also be flexible to match the feel of the rest of the ball. Its surface should be textured to increase grip.

[0032] **FIG. 1** of the drawings shows a pump exit nozzle **46** but does not show the one-way valve that is attached to this exit. Shown in **FIG. 4** is a one-way valve assembly **62** of the duckbill-type to be mounted in the exit nozzle **46**. This assembly comprises an inlet end piece **64**, an outlet end piece **66** and an elastomeric duckbill valve **68** captured between the two end pieces. The end pieces **64** and **66** are preferably plastic, such as a polycarbonate, and may be ultrasonically welded together.

[0033] Although any desired one-way valve can be used on the exit nozzle **46** and although duckbill valves are a common type of one-way valves, a specific duckbill configuration is shown in **FIG. 4** and in greater detail in **FIG. 5**. The duckbill structure **68** is formed of an elastomeric silicone material and is molded with a cylindrical barrel **70** having a flange **72**. Inside of the barrel **70** is the duckbill **74**, which has an upper inlet end **76** molded around the inside circumference into the barrel **70**. The walls or sides **78** of the duckbill **74** then taper down to form the straight-line lower end with the duckbill slit **80**. The duckbill functions in the conventional manner where inlet air pressure forces the duckbill slit open to admit air while the air pressure inside of the ball squeezes the duckbill slit closed to prevent the leakage of air. Such a duckbill structure is commercially available from Vernay Laboratories, Inc. of Yellow Springs, Ohio.

[0034] A pump assembly of the type described and illustrated in **FIGS. 1-5** is preferably made primarily from plastics such as polycarbonate or high impact polystyrene, most preferably from polycarbonate. Although the assembly is small and lightweight, perhaps only about 25 grams, it is desirable that a weight be added to the ball structure to counterbalance the weight of the pump mechanism.

[0035] Other forms of the invention may utilize different pump constructions and the precise sequence of manufacturing steps may vary in various forms of the invention. Those skilled in the art will recognize the substantial benefits including the economies of construction inherent in allowing the pumping mechanism to be designed to accommodate the environmental considerations inherent in normal use of the sports ball and not the much harsher conditions that are encountered during the manufacturing process.

[0036] In the context of basketball performance testing, rebound height is defined as the height the bottom of a basketball attains when dropped from 72 inches onto a wooden floor surface. (Although the description of the preferred embodiment is phrased in terms of a basketball, it will be understood that the invention has application to other sports balls, such as soccer balls, volleyballs, footballs and playground balls.) The performance characteristics can also be described in terms of a coefficient of restitution (COR). The mathematical relationship between rebound height and coefficient of restitution is described below in example 3. In a rebound test, the surface upon which the ball is dropped is designed to simulate a regulation basketball-playing surface, and it is a two-inch thick wooden piece securely attached to a foundation. The rebound height can vary for a particular ball when it is dropped on different spots on the ball. A useful measure of rebound height variability is the difference between the maximum rebound height and the minimum rebound height. It is a desirable feature to have basketball rebound height as uniform as possible when the ball is dropped repetitively with different orientations.

[0037] Player testing shows that basketballs with maximum minus minimum rebound height of five and one half inches or more are difficult to play with and control and are difficult to dribble. The basketballs with maximum minus minimum rebound height of five inches or less are acceptable for play and show no obvious dribbling problem. Basketballs with maximum minus minimum rebound height of four inches or less are preferred. Additionally, it has been found that a basketball generally must rebound to a height of between fifty and fifty-six inches overall to be acceptable, although individual preferred rebound height may vary from player to player.

[0038] The act of bouncing a basketball, or other sport ball, on a floor is a dynamic event with impact loading, elastic deformation and vibration. It should be remembered that bouncing a ball is only one way of impact loading a ball and that balls are impact loaded when they are struck by a foot, hand,-racquet, etc. In elastic collision, energy is conserved, which means that the energy of the ball prior to being impact loaded is equal to the energy of the ball after impact loading. Consider the situation in which a ball of mass "m" is dropped from a height "h" and bounced from a floor. Before the ball is dropped, all of the energy of the ball is potential energy (U), U=mgh, where "g" is acceleration due to gravity. Immediately at the point of contact at the floor, all of the potential energy of the ball has been converted to kinetic energy (V), $V=mv_o^2/2$, where v_o, is the velocity of the ball when it strikes the floor. At the point where the ball stops moving, the kinetic energy is entirely converted into elastic deformation of a ball. The elastic deformation is like loading a spring or diving board; it deforms, then it springs back. After motion stops (i.e., when the ball is at its maximum deformation), the energy stored in the deformation is released and all of the energy is converted into rebound velocity. The rebound velocity provides an ideal elastic ball enough energy to rise to the original drop height under perfect impact conditions.

[0039] In reality, collisions are not elastic, but energy is still conserved. When a real ball bounces from a floor, the final energy of the system can be given as the sum of the kinetic energy of the ball plus the vibrational energy of the ball plus potential energy of the ball plus other types of energy, wherein other types of energy are very small in relation to the initial energy and include energy imparted to the floor, acoustical energy, etc. The vibrational energy of the ball is proportional to the number of modes of vibration that are excited and the amplitude of the vibrations. Because energy must be conserved, when energy is pumped into vibrational energy during loading, that energy is not available as kinetic energy. The amount of energy that is converted into vibrational energy by loading is a function of where the loading occurs. In other words, different amounts of energy will be pumped into vibrational energy depending upon which portion of the ball bounces from the floor. It is therefore required to map the surface of the basketball such that rebound height is known for all points on the ball. Typical mapping of the entire surface of the ball will require rebound testing on each panel of the ball at approximately five points per panel. The panel where the pump is located will have additional points tested, generally at one-half to one inch increments along the panel. Additionally, the two ends of the ball are also tested. Each point is tested several times to find the points where the rebound height is an extremum, i.e., a maximum or a minimum rebound height. The difference between maximum and minimum rebound height can then be determined.

[0040] A "quick test" may be utilized once a full mapping scheme for a particular product has been determined. This quick test utilizes the data previously acquired when mapping the entire surface of the sport ball, and then tests only those locations where the maximum and minimum points are expected. Although the quick test is not as accurate, it may be utilized to quickly test the rebound characteristics of a sport ball at the locations where the rebound height is an extremum.

[0041] When studying the dynamics of a ball responsive to a loading force such as an impact due to bouncing, the nature of the impact loading and the natural modes of vibration of the ball are important. The natural modes of vibration of the ball include not only the vibrational modes of a conventional ball but also vibrational modes of internal components. Generally, it is the vibrational modes of the device **11** that is of most interest and which has the lowest frequency. As used herein, the term natural frequency of the ball is the lowest vibration frequency of the ball with the internal device installed in the ball.

[0042] Impact loading is the force acting on the ball to decelerate it to a stop on the floor, backboard, rim, etc. and cause the ball to bounce back. The quantities of interest are the force and time history. The natural frequency of the ball influences how fast and to what extent the ball will respond to the impact and how much of the impact energy will be stored in local ball vibrations. The period of vibration is the time required to complete one cycle of motion, which is inversely proportional to the frequency of vibration.

[0043] The inventors have now found that the ratio of two critical impact parameters are directly related to the maximum minus minimum rebound height. The two critical impact parameters are the duration of the ball's impact with the floor and the half period of a specific mode of vibration of the ball. The specific mode of vibration is a mode of vibration where the device swings in an oscillatory manner.

[0044] The critical ratio is most easily measured when the ball, with the device installed, is dropped on the spot that yields the minimum rebound height. As previously described herein, the minimum rebound height is found by mapping the surface of the ball. The "quick test" may be used once a surface is mapped for the same construction sport ball, but small changes to the component or the materials will require complete mapping to determine the proper locations that yield maximum and minimum rebound heights. As used herein, "critical ratio" refers to the half period of component vibration divided by the duration of the ball's impact with the floor. (Although this description is most relevant to a basketball and a pump, it will be understood that the invention has application to other sport balls and other components, preferably other sport balls with a

[0045] pump.) The duration of the ball's impact with the floor can be measured with high speed digital imaging. It will be understood that the duration refers to the duration of contact of the ball with the floor, and the duration of impact does not appreciably vary with drop location. The duration of impact should be measured at the location yielding the minimum rebound height. The ball's impact with the floor is first captured with the high speed digital imaging-system. A frame sampling rate of about 9,000 to 13,500 frames per second is preferably recommended. Analysis of the set of images will indicate the number of image frames during which the ball is in contact with the floor. The duration of the impact event is simply the total number of frames that the ball is in contact with the floor divided by the frame sampling rate.

[0046] The half period of vibration of a basketball or other sport ball can also be measured using high speed digital imaging. Analysis of the set of images allows the determination of the number of frames that it takes for the device to swing from one endpoint to the other endpoint, wherein an endpoint is where the swinging motion of the device stops and reverses. The half period of vibration for a basketball having a self-contained inflation device is simply the total number of frames between the endpoints divided by the frame sampling rate.

[0047] An alternate method may be used to determine the half period of component vibration such as measuring the entire period and dividing by two. For example, the entire period of vibration can be measured by counting the number of frames between when the device is at an endpoint and when it returns to that endpoint. Alternatively, as known by those skilled in the art, the period of vibration can also be determined by measuring the natural frequency directly with an accelerometer.

[0048] In one embodiment, the duration of the impact loading can also be determined using high speed digital imaging. The duration is simply the number of frames between when the ball first makes contact with the floor and when the ball leaves the floor divided by the frame sampling rate. Alternatively, dropping the ball onto a load cell and measuring the force over time may be used to measure the duration of the ball's impact.

[0049] **FIG. 6** illustrates test data for a plurality of basketballs. For each basketball, the maximum minus the minimum rebound height was determined by mapping the surface of the basketball and the corresponding delta COR was then calculated, wherein delta COR is defined as the maximum minus the minimum COR for tested portions of the ball. Thereafter, the critical ratio for each of these basketballs was determined by testing. Each point or dot in the diagrammatic view of **FIG. 6** represents the test results for a single basketball. These test results corroborate decisively a strong negative correlation between the critical ratio and the difference between maximum and minimum rebound height. More particularly, **FIG. 6** establishes that the maximum minus minimum rebound height increases as the critical ratio decreases.

[0050] In other words, the parameter that best correlates to maximum minus minimum rebound height for any specific basketball is the critical ratio, i.e., the half period of vibration for a basketball having a self-contained inflation device divided by the duration of the ball's impact with the floor. The quotient of these numbers is referred to herein as the critical ratio. When this critical ratio is less than 0.95 for a regulation basketball, the maximum minus minimum rebound height is generally greater than five and one half inches, and the ball is therefore likely to be unacceptable for play due to dribbling problems. When this critical ratio is greater than or equal to 0.95, the maximum minus minimum rebound height is generally less than or equal to five inches, and the ball is therefore suitable for play. This critical ratio can be used in the design and development phase, as well as during quality control, to determine if an inflated ball will have rebound problems. If necessary, design changes may be made to minimize the vibration before producing balls to be sold to customers.

[0051] Examples of the factors that affect the critical ratio include, but are not limited to, the stiffness modulus, flex modulus, bulk modulus, tension modulus and compression modulus values of each of the components of the ball, including the panels, carcass, bladder, windings, and housing **20**; the inertia and mass of the pump or other internal component, the local stiffness of the component's support, the air pressure in the ball, and the quality of the bond between the component's housing (the "boot") and the bladder and cover.

[0052] If a ball design is tested and does not conform to the desired specification as to rebound characteristics, COR and/or critical ratio, then the design is modified in a manner that changes the frequency of vibration of the internal device. This is normally done to avoid resonance and may involve either increasing or decreasing the frequency of vibration of the device. The resonance that is sought to be avoided is resonance with one half the loading frequency. One design modification that can be made is to add mass to the device or to reduce the mass of the device. Generally, it is preferable to change the mass of the device at the end that is distal from the housing. Other examples for a device of a specific design involve the modification of the housing such as changing the composition of the housing material, changing its modulus of elasticity or changing the thickness of the mounting material. The groove **25** can also be enlarged or reduced to change the frequency of vibration.

[0053] **FIGS. 8A-8E** represent snapshots of a computer simulation using finite element analysis for understanding the dynamics of a basketball having an internal device such as a pump. In **FIG. 7A**, a virtual basketball **100** is approximately a fraction of inch above a virtual floor **104**. In the computer simulation, the virtual basketball **100** has the velocity and the acceleration of a real basketball dropped from the height of 72 inches. The virtual basketball **100** includes a virtual pump **102** that is coupled to a virtual boot **112**. The virtual boot **112** includes a virtual flange **116** that couples the virtual boot **112** and the virtual pump to the virtual basketball **100**.

[**0054**] The virtual basketball **100** is aligned such that a portion **106** initially impacts with the virtual floor **104**. If the virtual basketball **100** is to scale, then the distance from the portion **106** to a point **108** is approximately one and one-half inches. Point **108** is defined as the intersection of the longitudinal center axis **114** of the virtual pump **102** and the surface **110** of the virtual basketball **100**.

[**0055**] In **FIG. 7B**, the virtual basketball **100** has impacted the virtual floor **104** and partially deformed. The orientation of the virtual pump **102** with respect to the virtual basketball **100** is approximately unchanged from **FIG. 7A**. In other words, the virtual pump **102** is still in its equilibrium position and is approximately radially aligned with the center of the basketball. In **FIG. 7C**, the virtual basketball **102** is approximately at its maximum deformation. Due to the deformation, the orientation of virtual boot **112** is changed from its orientation in previous figures. Now it is orientated such that it is approximately vertical, which causes the virtual pump **102** to rotate to an approximately vertical position.

[**0056**] In **FIG. 7D**, the virtual basketball **100** has rebounded from the virtual floor **104**, and the inertia of the virtual pump **102** causes it to continue to swing past vertical.

[**0057**] In **FIG. 7E**, the virtual pump **102** continues to oscillate and currently has swung past its equilibrium position, as illustrated in **FIG. 7A**. The virtual pump **102** will continue to swing back and forth until the energy in that mode of vibration is damped out. The results of the computer simulation were experimentally verified using prototype basketballs. From experimental evaluation and testing involving both computer simulation and actual basketballs it was determined that the amount of energy that was pumped into the swinging mode of vibration of the pump was dependent upon at least two factors: (1) the location of the loading in relationship to the pump; and (2) the stiffness of the boot **112** including the flange **116**. It was found experimentally that if the boot and flange were not stiff, then the pump did not swing as much as if the boot and flange were stiff. By providing for the boot and flange to be of appropriate stiffness, the oscillatory mode of vibration was essentially decoupled from the loading force applied to the basketball.

[**0058**] Referring back to **FIG. 1**, as previously described, the housing **20** includes a groove **25**, which circumscribes the housing **20**. The groove **25** provides surprising and unexpected structural stability to the housing **20**. In testing, basketballs, which had boots that did not include the groove **25**, were repeatedly bounced approximately 30,000 times. After repeatedly bouncing the test basketballs, the housings without a groove formed therein failed. Test basketballs that included housings having the groove **25** formed therein do not fail at the same rate as basketballs that do not have the groove **25**.

EXAMPLE 1

[**0059**] A regulation size synthetic leather basketball was made having a diameter of 9.43 inches (23.95 cm), a circumference of 29.5 inches (75 cm), a weight of about 600 grams. The ball contained an integral pump of the type shown in **FIGS. 1-5**. The pump was configured to increase the pressure of the ball by at least 1 psi for every 200 pump strokes. The rebound of the ball when it was dropped from a height of 72" (measured from the bottom of the ball) onto a wooden surface designed to simulate the floor of a basketball court was determined when the ball was dropped repeatedly with different orientations. The ball was found to have a rebound height in the range of 50-57 inches on all panels of the ball (measured from the top of the ball), with a difference between the maximum and minimum rebound heights of 5.5 inches or less. The lowest rebound height resulted when the portion of the ball surface that was located about 2 inches away from the pump was the part that contacted the wooden surface.

EXAMPLE 2

[**0060**] The procedure of Example 1 was repeated with a second basketball of the same type, and the second basketball was found to have a rebound height in the range of 50-54 inches on all panels of the ball (measured from the top of the ball), with a difference between the maximum and minimum rebound heights of 4 inches or less.

EXAMPLE 3

[**0061**] The coefficient of restitution (COR) corresponding to various rebound heights for the balls described in Examples 1 and 2 was determined according to the following formula:

$$COR=V_H/V_I$$

[**0062**] wherein

[**0063**] V_I is the downward velocity of the ball upon initial impact with the floor, and

[**0064**] V_H is the velocity of the ball as it travels upward immediately after impact with the floor.

[**0065**] The velocity for an object that is dropped from rest and which is traveling vertically can be defined by the equation:

$$v^2=2ax,$$

[**0066**] where v is velocity, a is acceleration due to gravity, x is the distance to the floor from the top of the ball at the initial drop point.

[**0067**] More specifically, $V_I=\sqrt{2(\mathbf{32}\text{ft/s}^2)(12\text{in./ft})(x\text{in.})}$

[**0068**] And $V_H=\sqrt{2(\mathbf{32}\text{ft/s}^2)(12\text{in./ft})(h\text{in.})}$

[**0069**] Stated another way, $V_H/V_I=\sqrt{h/x}$,

[**0070**] wherein, h is the rebound height.

[**0071**] Furthermore, delta COR was determined by subtracting the COR corresponding to the minimum rebound height of a particular ball from the COR corresponding to the maximum rebound height of the same ball. The calculated velocity, COR and delta COR results are shown below in Table 1. Thus, a ball with a rebound of 50 inches has a COR of 0.7506, and a ball with a rebound of 54 inches has a COR of 0.7868. The ball of Example 1 was found to have a delta COR of 0.051. The ball of Example 2 was found to have a delta COR of 0.036. Thus, for both of these balls, the maximum and minimum COR values for any single measurement were in the overall range of 0.750-0.813.

TABLE 1

COR for Basketball Rebound Height Test

	Height (in)	Velocity (in/sec)	COR (n/a)
Initial	72	235.88	—
Rebound	40	153.70	0.6516
	41	156.20	0.6622
	42	158.65	0.6726
	43	161.07	0.6828
	44	163.45	0.6929
	45	165.80	0.7029
	46	168.11	0.7127
	47	170.39	0.7224
	48	172.65	0.7319
	49	174.87	0.7413
	50	177.07	0.7506
	51	179.24	0.7598
	52	181.38	0.7689
	53	183.50	0.7779
	54	185.59	0.7868
	55	187.66	0.7956
	56	189.71	0.8042
	57	191.73	0.8128
	58	193.74	0.8213
	59	195.72	0.8297
	60	197.69	0.8381
	Min (in)	**Max (in)**	**Delta COR (n/a)**
Rebound	50	55	0.0449
Rebound	51	56	0.0444
Rebound	52	57	0.0439
Rebound	53	58	0.0434

[0072] The invention has been described with reference to the preferred embodiments. Modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such alterations and modifications insofar as they come within the scope of the claims and the equivalents thereof.

What is claimed:

1. A ball comprising:

a carcass having at least one layer of material, the carcass defining an exterior surface and a generally hollow interior;

a device having an top and a bottom, wherein the device extends into the generally hollow interior of the carcass; and

a housing having an upper end with a flange extending therefrom and a lower end, the housing defining a central opening extending between the upper end and lower end of the housing, wherein the device is received by the central opening of the housing and extends therefrom, wherein the flange is coupled to the at least one layer of material and the lower end is disposed within the hollow interior of the carcass, and wherein the natural frequency of oscillation of the housing with the device coupled thereto is not in resonance with a predetermined loading force such that the performance characteristics of the ball are within an allowable range from specified performance characteristics for a second ball, the second ball defining a second housing that does not include a second device therein.

2. The ball of claim 1, wherein the housing defines a groove circumscribing the housing.

3. The ball of claim 1, wherein the ball is a basketball having a coefficient of restitution in the range of 0.750 to 0.813.

4. The ball of claim 3, wherein the ball has multiple values for the coefficient of restitution, and wherein the difference between the largest and smallest values of coefficient of restitution for the ball is equal to or less than 0.051.

5. The ball of claim 4, wherein the ball has multiple values for the coefficient of restitution, and wherein the difference between the largest and smallest values of coefficient of restitution for the ball is equal to or less than 0.036.

6. A method of testing a hollow ball, the method comprising the steps of:

providing a carcass, the carcass defining an exterior surface and a generally hollow interior, wherein the carcass includes at least one layer of material;

providing a device;

coupling the device to the at least one layer of material, wherein the device extends generally inward from the one layer of material and is substantially disposed into the generally hollow interior; and

providing a loading force that deforms at least a portion of the ball; and

determining whether the device oscillates at a frequency that is in resonance with the loading force.

7. The method of claim 6, further including the steps of:

responsive to determining whether the device oscillates at a frequency that is in resonance, altering the natural frequency of oscillation of the device.

8. The method of claim 7, wherein the natural frequency of oscillation of the device is altered by changing the mass of the device.

9. The method of claim 7, wherein the natural frequency of oscillation of the device is altered by changing the distribution of the mass of the device.

10. The method of claim 7, wherein the natural frequency of oscillation of the device is altered by changing the coupling of the device to the at least one layer of material.

11. The method of claim 7, wherein device is coupled to the at least one layer using a housing having the device extending therethrough, wherein the coupling is altered by changing the housing.

12. The method of claim 11, wherein the change in the housing involves a change in at least one of the flex modulus, bulk modulus, tension modulus, and compression modulus of the housing.

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