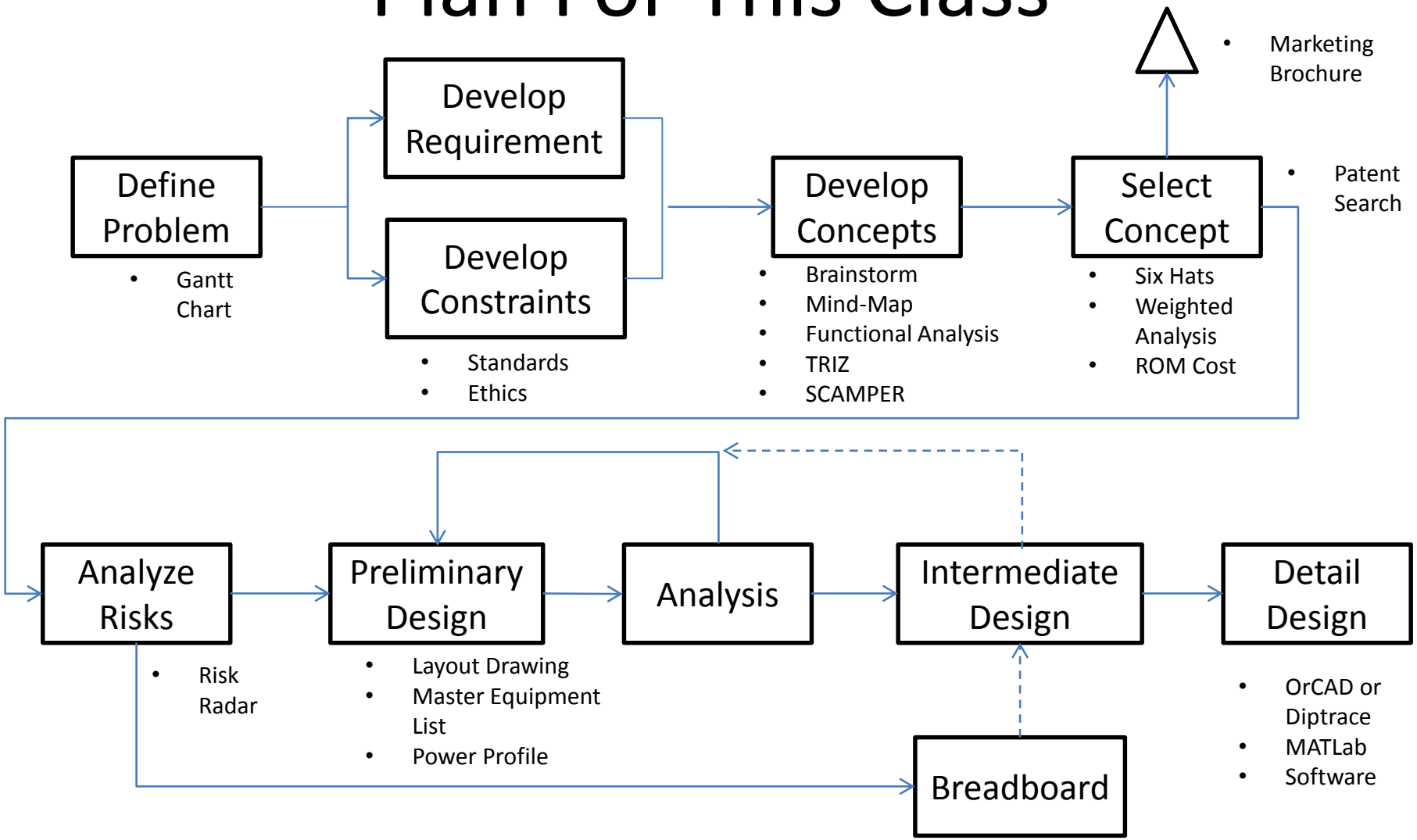
Elec 4309 Senior Design

Wendell H Chun

Sept. 19, 2017

Plan For This Class



True Inventions

- Part of the problem is that we're talking about two sides of the same coin.
- Every new idea has elements that are purely new, that never existed before. But it also has elements that already existed.
- E.H. Gombrich stated that we simply can't think of things that we haven't got some model for already in our head.
- Most of the time when somebody creates something new they have built it from pieces of things they've seen before.
- That doesn't take away from the novelty, but it does add a complexity of continuity.
- To replicate the innovation process you must appreciate the role of continuity, or how ideas draw on the past.

Intellectual Property (IP)

- IP refers to the bundle of legal rights that arise from the creative genius of the human mind
- Real and personal property rights protect one's ownership interest in **tangible objects**
- IP rights protect one's ownership interest in **intangible objects**, such as the idea behind an invention, the music score for a Broadway play and the name or logo used to brand a product

Types of IP

- Types of IP:
  - property rights
  - patents
  - trademarks
  - copyrights
- IP rights reward and protect the creative works of inventors, authors, owners and sellers of goods and services in the marketplace
- An award of patent, trademark or copyright protection requires a delicate balance between the interests of the inventor or author, and the interest of society as a whole

Competitive Market

- Intellectual property rights foster a competitive marketplace.
- Encourage **disclosure** of innovation through protecting the fruits of that innovation for a period of time.
- Disclosure allows others to build and improve upon prior innovation so that the state of the art continues to evolve and develop
- Without the benefits provided by intellectual property protection, the market place would not operate as effectively
- Imagine what the world would be like if every competitor had to continuously "reinvent the wheel" rather than being able to refine and improve upon the works of others

Regional Protection

- Intellectual property rights are regional in nature and the conditions of their grant and enforceability are governed by the laws of each jurisdiction
- A U.S. patent can be only granted and enforced in accordance with the laws of the United States
- A trademark can only be registered and enforced in Canada in accordance with the laws of Canada, and a copyright can only be registered and enforced in Mexico in accordance with its laws
- Countries have different approaches to intellectual property rights protection
- Variations in the procedure for obtaining IP rights account for a large percentage of these differences, rather than the differences in the substantive rights granted in each country.

Patents & Trademarks

- The words "patent" and "trademark" are often used interchangeably
- The two words have very different meanings and refer to very different forms of intellectual property rights
- These words can seldom be used interchangeably, as the underlying rights that each protects is quite different in nature

What is a Patent?

- A patent is used to protect the intellectual property rights associated with the design of a product or process
- U.S. patents are issued by the United States Patent and Trademark Office (USPTO) and are enforceable only within the U.S. and its possessions.
- A patent gives the patent owner the "exclusive right" to stop others from making, using, selling or offering for sale the product, or process of making the product, that is described by the patent claims

What is a Patent?

- Important to note that a patent does not give the patent owner the right to exploit the patented invention himself
- Patent owner has only the "exclusive right" to stop others from doing so
- Just because you obtain a patent on your product does not mean that you can actually use the product because you may be blocked by an earlier patent owner who exercises the "exclusive right" granted to him under his patent
- Term for a patent is 20 years from the filing date of the patent application, which results in the granting of the patent

What are Trademarks?

- Trademark registrations in the U.S. are issued by the United States Patent and Trademark Office
- Patent protects a product from unauthorized copying through the patent owner's exclusive right to stop others from making, using, selling or offering for sale the patented product, while a trademark addresses the need for product identification, or branding, among consumers of the product
- A trademark has nothing to do with preventing a product from being copied. That is the role of a patent.

Trademarks

- A trademark is defined as "any word, name, symbol, or device, or any combination, used, or intended to be used, in commerce to identify and distinguish the goods of one manufacturer or seller from goods manufactured or sold by others, and to indicate the source of the goods
- A trademark is a brand name that identifies the source of a product
- A service mark identifies the source of a service
- A collective mark is a trademark or service mark that is used by a group or organization
- A certification mark is a mark used by someone other than the mark's owner to certify quality, accuracy or other characteristics of the user's goods or services.

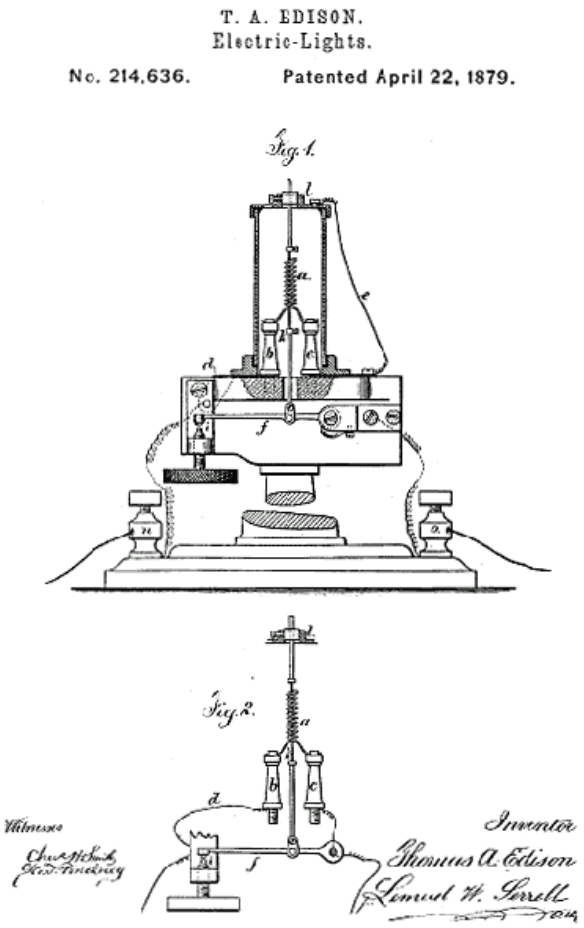
What is a Copyright?

- Unlike a patent which protects the idea itself, the copyright protects only the expression.
- In order to qualify for copyright protection, a work must be original to the author
- To be original, the work:
  - Must have been independently created by the author rather than being copied from other work(s)
  - Must have at least a minimal degree of creativity
- If these two conditions are not met, the work will not qualify as being original and is not entitled to copyright protection
- However, a work still qualifies for copyright protection even if it includes non-original elements
- Depending on when the work was created, the period of copyright protection begins when the work is created and terminates 70 years after the death of the author

Patents

How Patents Work

- When inventors come up with a new device, the first thing they want to do is **patent** it.
- Patents are a government's way of giving an inventor ownership of his or her creation
- For a certain period of time, patent-holders are allowed to control how their inventions are used, allowing them to reap the financial rewards of their work
- Patents are a palpable, legally-binding manifestation of a person's genius and innovation; they allow a person to actually own an idea.


T. A. EDISON.
Electric-Lights.
No. 214,636. Patented April 22, 1879.
Fig. 1.
Fig. 2.
Witnesses
Inventor
Thomas A. Edison
Samuel W. Sewall

Patent Protection

- Patents are the most complicated type of intellectual property, as well as the most restrictive
- To patent an invention, you have to meet a number of requirements
- The invention must be sufficiently **novel:**
  - it must be substantially unlike anything that is already patented
  - has already been on the market
  - has been written about in a publication
- You can't even patent your own invention if it has been on the market or discussed in publications for more than a year

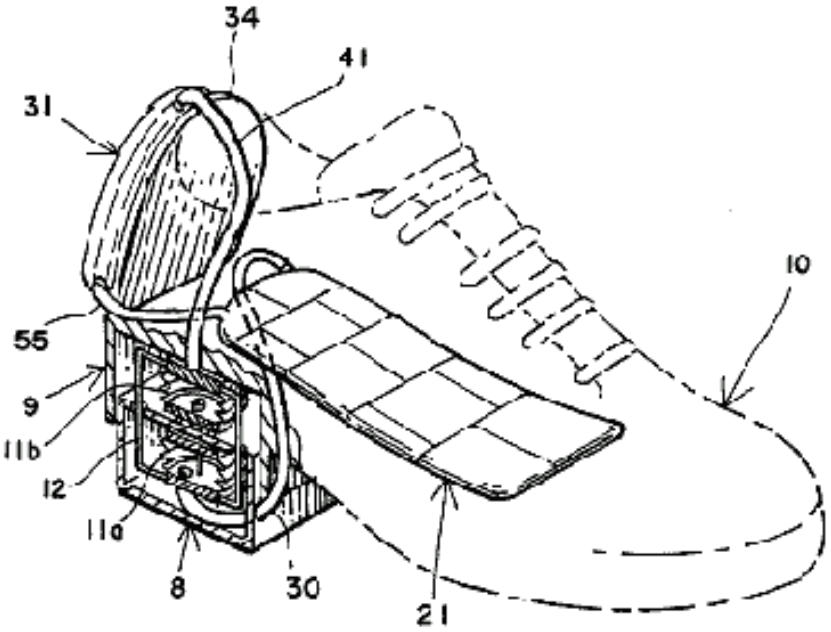


FIG. 2

Patent Protection

- The vast majority of inventions are actually improvements on existing technology, not wholly new items
- Adaptations of earlier inventions can be patented as long as they are **nonobvious**, meaning that a person of standard skill in the area of study wouldn't automatically come up with the same idea upon examining the existing invention
- For an invention to be patented, it must be innovative to the point that it wouldn't be obvious to others
- Another condition for patenting something is that the invention is "**useful**"
- Unproven ideas generally fall into the realm of science fiction, and so are protected only by copyright law

Patent Protection

- The "useful" clause may also be interpreted as a prohibition against inventions that can only be used for illegal and/or immoral practices
- For the life of the patent (20 years in the United States), patent-holders can profit from their inventions by going into business for themselves or licensing the use of their invention to other companies
- It is up to the patent-holder to actually enforce the patent (the government does not go after patent or copyright infringers)
- To enlist the government's help in stopping infringement, the patent-holder must take any infringers to court
- While patent law does protect most forms of invention, it does not apply to all great ideas

What You Can Patent

- In patent law, the term "invention" is defined loosely so that it can encompass a wide variety of objects
- If patents have to apply to things that don't exist yet, then the legal language must be fairly vague.
- In addition to standard technological machines and machine advancements, you can also patent certain computer programs, industrial processes and unique designs
- No matter how innovative and beneficial they may be, certain notions are automatically public property the minute they are uncovered:
  - Scientists cannot patent laws of the universe, even though defining those laws may revolutionize a particular industry or change how we live. (This principle existed long before humans did, so, logically, it cannot be any person's intellectual property)

What You Can Patent

- Some sorts of ideas are considered outside the realm of patents
- Scientists cannot patent a newly discovered plant or animal, either, though they may be able to patent a new plant or animal that was produced through genetic engineering
- This is similar to the patenting of processes and computer programs:
  - A genetic engineer didn't create any of the parts, but the combination of these parts may be novel and nonobvious, and therefore patentable
- In addition to giving proper credit to individual inventors, patents help out humanity in general

Functions of Patents

- Patents encourage the advancement of science and technology in two major ways:
  - They give inventors an opportunity to profit from their creations. The process of inventing a new device or process is an extremely difficult one, and few people would go through it if there weren't any financial reward.
  - They help disseminate technological information to other inventors. When you apply for a patent, you are required to submit a detailed description of your invention. This description becomes part of the patent office's database, which is public record.

- Patents motivate individual inventors, but they also motivate large companies

Functions of Patents

- A patent’s success might be wholly dependent on having exclusive rights to innovative products
- Intellectual property makes up a huge chunk of these companies' assets
- When something is invented as part of a person's work for a company, the company is typically given control over the invention, though the patent may officially go to the individual inventor
- If you are contracted to grant your employer all patent rights to your work, selling your own invention would actually be infringing on your own patent (and your employer could take you to court)

Patent Process

1. The first thing you need to do is search the United States Patent and Trademark Office's patent database to see what similar ideas have been patented
2. If you have determined that your idea is new, then
3. Three options in order to proceed:
   - Retain a **patent lawyer**. Patent lawyers are attorneys with a science or technical degree who have met the patent office's qualifications (their professional credentials have been reviewed and they have passed a qualifying test).
   - Retain a **patent agent**. Patent agents are people who have met the patent office's qualifications but are not recognized as attorneys.
   - Some inventors work through the patent process themselves (called working *pro se*)

What a Patent Lawyer Does

- First thing the lawyer wants to do is review your idea in minute detail
- Once the lawyer is familiar with your invention, the lawyer begins a thorough patent search to uncover all of the related ideas that have already been patented
- The lawyer determines if your idea is patentable
- If the lawyer believes that you should proceed, the lawyer starts putting the patent application together

Patent Application

- Made up of a number of different parts
- Application must include:
  - A list and description of any "prior art," earlier inventions that are relevant to your invention
  - A brief summary outlining the new invention
  - A description of the "preferred embodiment" of the invention (This is a detailed account of how your idea will actually be put into practice including drawings)
  - One or more "claims" (Claims are the most important element of the application, as they are the actual legal description of your invention)
- Upon completion of the draft of your application. The lawyer shows it to you and you work together to correct any errors
- The application is sent to the U.S. Patent Office, along with a submission fee
- The patent application is either accepted or rejected. If rejected, the patent application can be amended and submitted for a second review

Maintaining a Patent

- Once the examiner is satisfied with your application, the inventor is issued a "Notice of Allowance."
- Pay the patent fee
- During the life of the patent, the inventor has to pay periodic **maintenance fee**
- The entire patenting process can take anywhere from a year to five years.
- The life of the patent actually begins at the application date and not the approval date

Maintaining a Patent

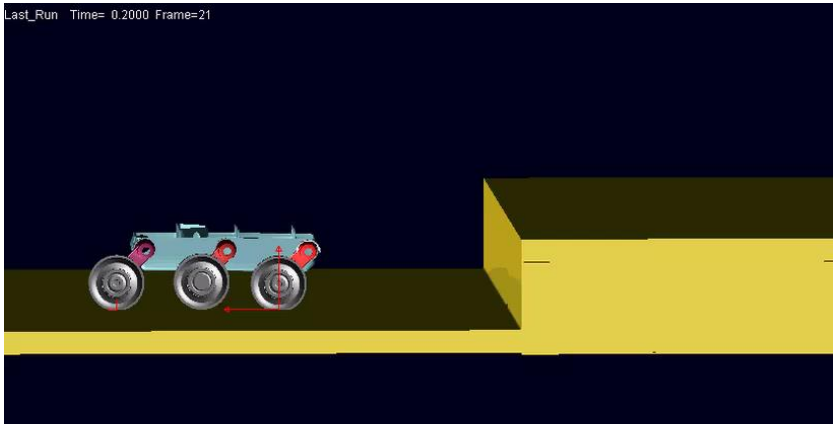
- Whoever completes an original invention first is granted the patent
- If two or more inventors submit the same invention around the same time, the patent office must declare an "interference" - a trial-like proceeding that determines who was the first inventor
- If your invention is of worldwide interest, you might consider applying for patents in other countries
- Patenting an invention is no easy task, but it is a necessary element in the life of an inventor

My Example:

Unmanned Ground Combat Vehicle

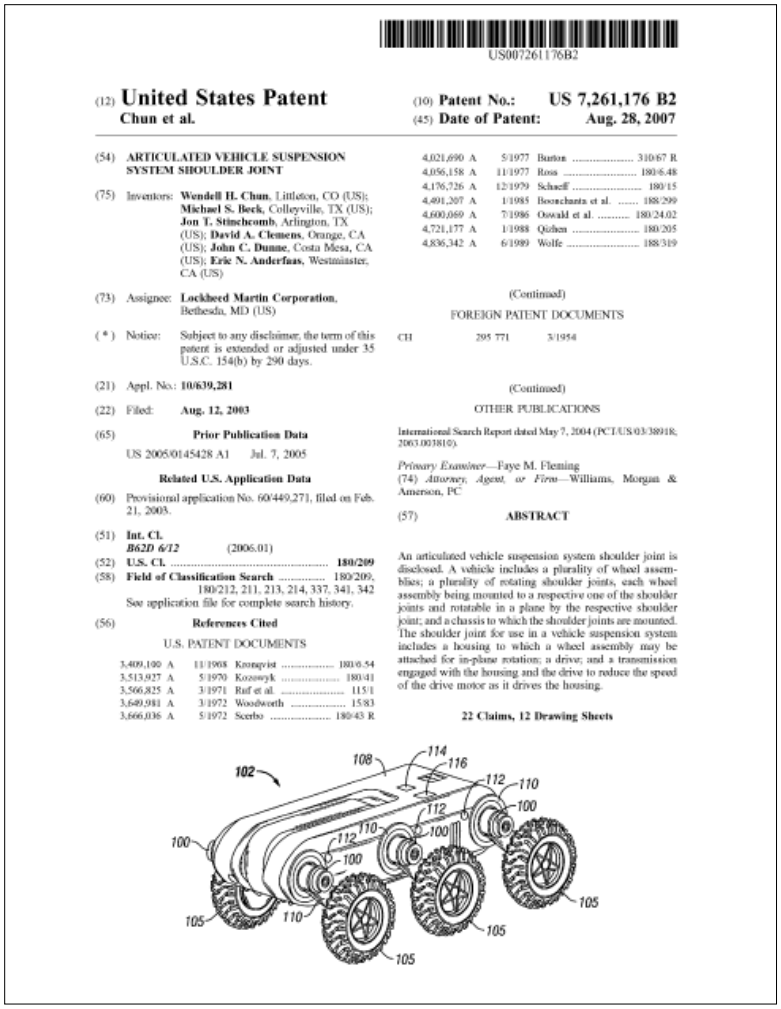
Lockheed Martin – CY 2000

- DARPA and the Army are jointly funding the UGCV program, which is being managed by DARPA.
- This program seeks to explore the performance gains enabled by designing combat vehicles without the constraints of accommodating an onboard crew.
- Primary performance metrics for the UGCV program are: (1) endurance; (2) mobility, and (3) payload fraction.
- Additional secondary metrics include: (1) airdrop-ability; (2) robustness to crash; (3) reliability; (4) signature, and (5) cost.



Unmanned Ground Combat Vehicle (for DARPA)

Patent No: US 7,261,176 B2



US007261176B2

(12) **United States Patent**
Chun et al.

(10) **Patent No.: US 7,261,176 B2**
(45) **Date of Patent: Aug. 28, 2007**

(54) **ARTICULATED VEHICLE SUSPENSION SYSTEM SHOULDER JOINT**

(75) Inventors: **Wendell H. Chun**, Littleton, CO (US); **Michael S. Beck**, Colleyville, TX (US); **Jon T. Stinchcomb**, Arlington, TX (US); **David A. Clemens**, Orange, CA (US); **John C. Dunne**, Costa Mesa, CA (US); **Eric N. Anderfaas**, Westminster, CA (US)

(73) Assignee: **Lockheed Martin Corporation**, Bethesda, MD (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 290 days.

(21) Appl. No.: **10/639,281**

(22) Filed: **Aug. 12, 2003**

(65) **Prior Publication Data**

US 2005/0145428 A1 Jul. 7, 2005

Related U.S. Application Data

(60) Provisional application No. 60/449,271, filed on Feb. 21, 2003.

(51) **Int. Cl.**
B62D 6/12 (2006.01)

(52) **U.S. Cl.** **180/209**

(58) **Field of Classification Search** 180/209, 180/212, 211, 213, 214, 337, 341, 342
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,409,100	A	11/1968	Kronqvist	180/6.54
3,513,927	A	5/1970	Kozowyk	180/41
3,566,825	A	3/1971	Ruf et al.	115/1
3,649,981	A	3/1972	Woodworth	15/83
3,666,036	A	5/1972	Scerbo	180/43 R
4,021,690	A	5/1977	Burton	310/67 R
4,056,158	A	11/1977	Ross	180/6.48
4,176,726	A	12/1979	Schaeff	180/15
4,491,207	A	1/1985	Bourchanta et al.	188/299
4,600,069	A	7/1986	Oswald et al.	180/24.02
4,721,177	A	1/1988	Qizhen	180/205
4,836,342	A	6/1989	Wolfe	188/319

(Continued)

FOREIGN PATENT DOCUMENTS

CH	295 771	3/1954

(Continued)

OTHER PUBLICATIONS

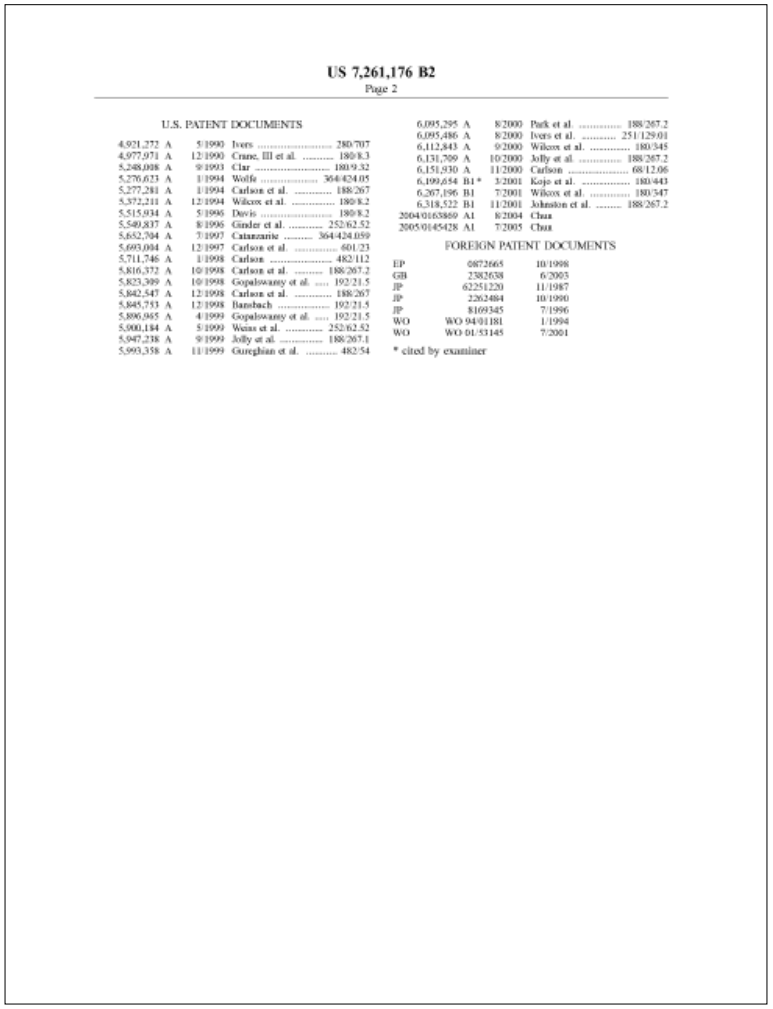
International Search Report dated May 7, 2004 (PCT/US/03/38918; 2003.003810).

Primary Examiner—Faye M. Fleming
(74) *Attorney, Agent, or Firm*—Williams, Morgan & Amerson, PC

(57) **ABSTRACT**

An articulated vehicle suspension system shoulder joint is disclosed. A vehicle includes a plurality of wheel assemblies; a plurality of rotating shoulder joints, each wheel assembly being mounted to a respective one of the shoulder joints and rotatable in a plane by the respective shoulder joint; and a chassis to which the shoulder joints are mounted. The shoulder joint for use in a vehicle suspension system includes a housing to which a wheel assembly may be attached for in-plane rotation; a drive; and a transmission engaged with the housing and the drive to reduce the speed of the drive motor as it drives the housing.

22 Claims, 12 Drawing Sheets



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U.S. PATENT DOCUMENTS

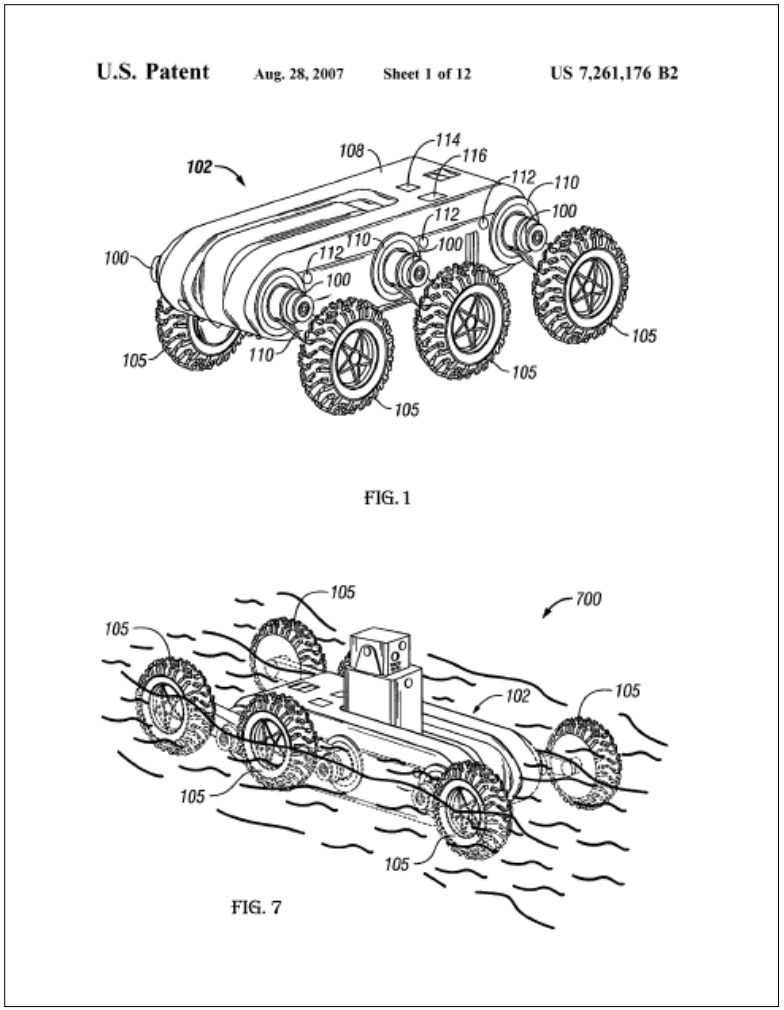
4,921,272	A	5/1990	Ivers	280/707
4,977,971	A	12/1990	Crane, III et al.	180/8.3
5,248,008	A	9/1993	Clar	180/9.32
5,276,623	A	1/1994	Wolfe	364/424.05
5,277,281	A	1/1994	Carlson et al.	188/267
5,372,211	A	12/1994	Wilcox et al.	180/8.2
5,515,934	A	5/1996	Davis	180/8.2
5,549,837	A	8/1996	Ginder et al.	252/62.52
5,652,704	A	7/1997	Catanzarite	364/424.059
5,693,004	A	12/1997	Carlson et al.	601/23
5,711,746	A	1/1998	Carlson	482/112
5,816,372	A	10/1998	Carlson et al.	188/267.2
5,823,309	A	10/1998	Gopalswamy et al.	192/21.5
5,842,547	A	12/1998	Carlson et al.	188/267
5,845,753	A	12/1998	Bansbach	192/21.5
5,896,965	A	4/1999	Gopalswamy et al.	192/21.5
5,900,184	A	5/1999	Weiss et al.	252/62.52
5,947,238	A	9/1999	Jolly et al.	188/267.1
5,993,358	A	11/1999	Gureghian et al.	482/54
6,095,295	A	8/2000	Park et al.	188/267.2
6,095,486	A	8/2000	Ivers et al.	251/129.01
6,112,843	A	9/2000	Wilcox et al.	180/345
6,131,709	A	10/2000	Jolly et al.	188/267.2
6,151,930	A	11/2000	Carlson	68/12.06
6,199,654	B1 *	3/2001	Kojo et al.	180/443
6,267,196	B1	7/2001	Wilcox et al.	180/347
6,318,522	B1	11/2001	Johnston et al.	188/267.2
2004/0163869	A1	8/2004	Chun	
2005/0145428	A1	7/2005	Chun	

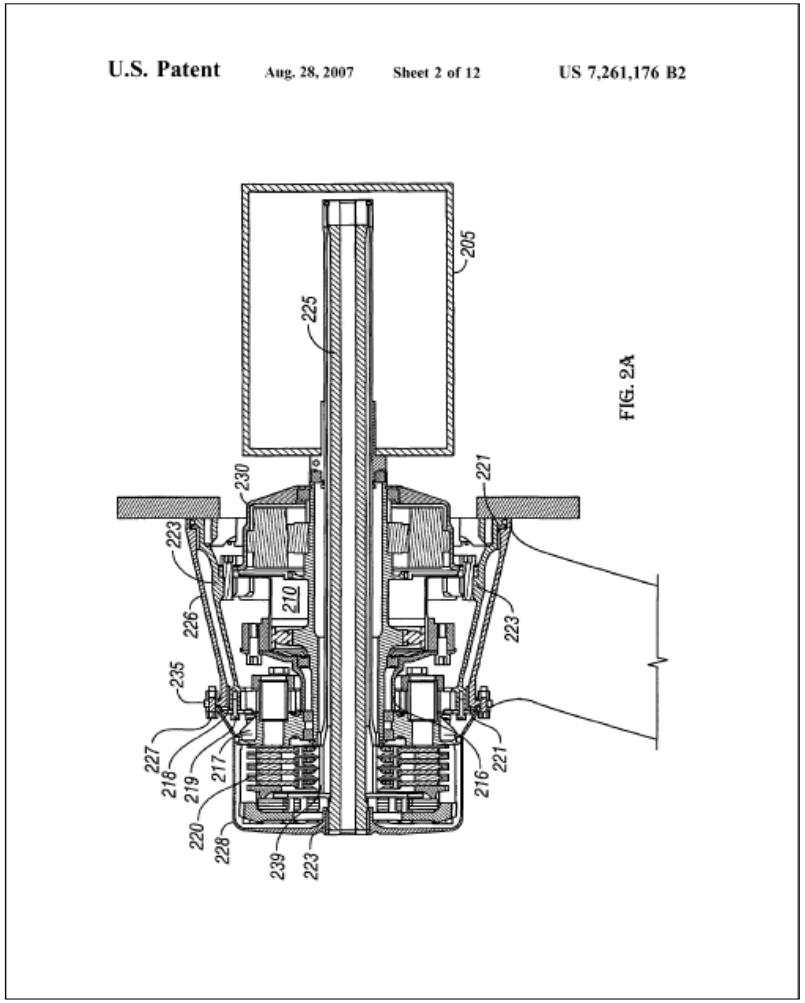
FOREIGN PATENT DOCUMENTS

EP	0872665	10/1998
GB	2382638	6/2003
JP	62251220	11/1987
JP	2262484	10/1990
JP	8169345	7/1996
WO	WO 94/01181	1/1994
WO	WO 01/53145	7/2001

* cited by examiner

Patent No: US 7,261,176 B2





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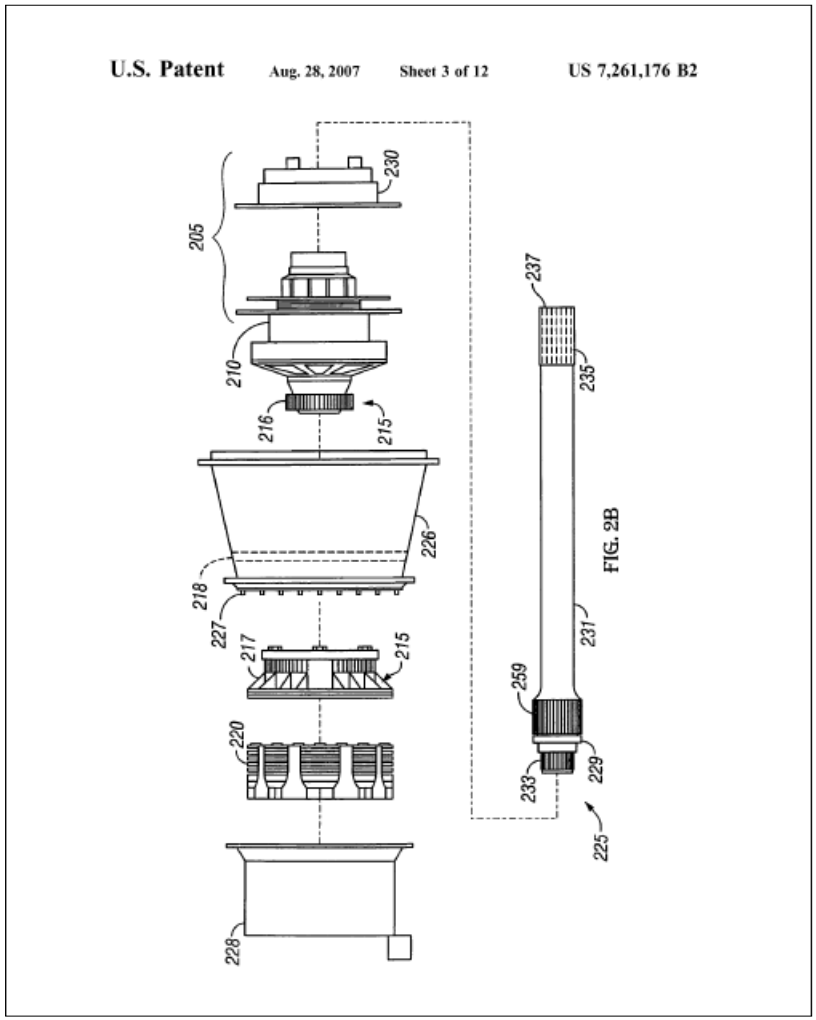
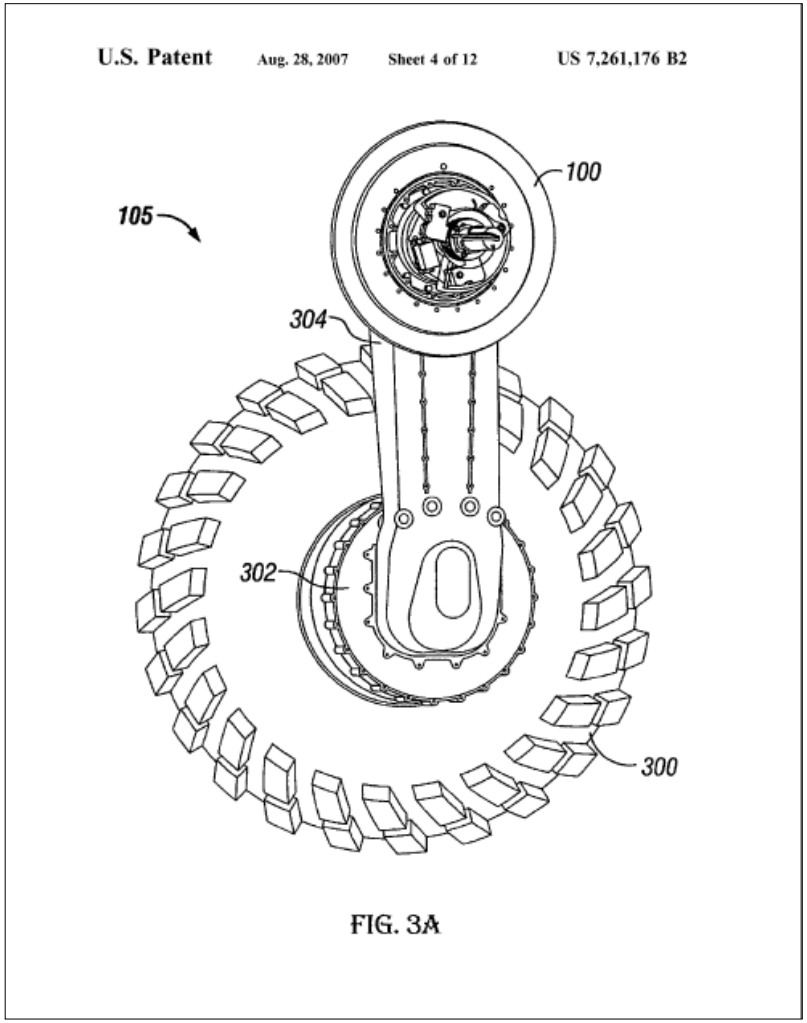
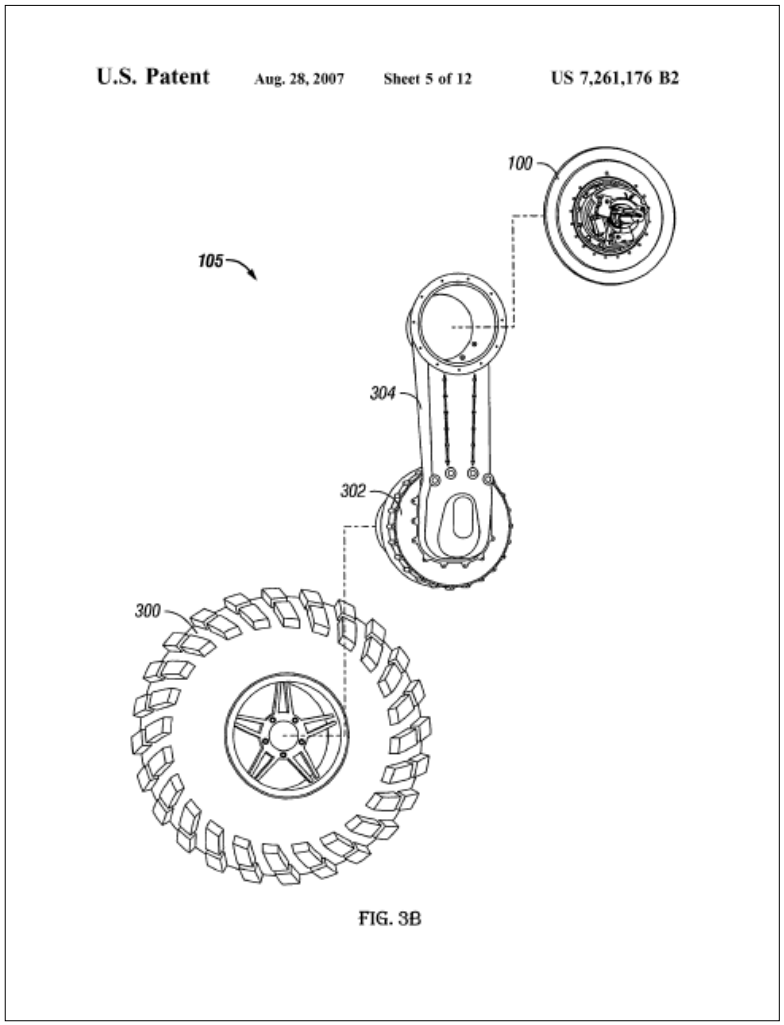
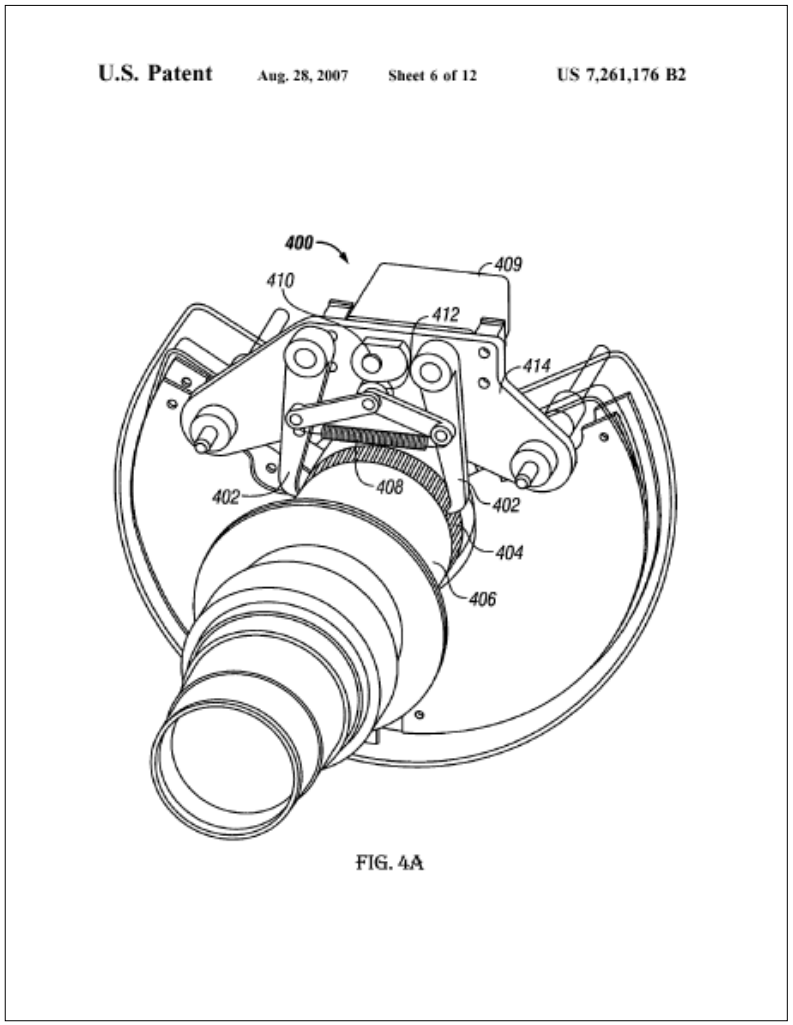




Patent No: US 7,261,176 B2





Patent No: US 7,261,176 B2

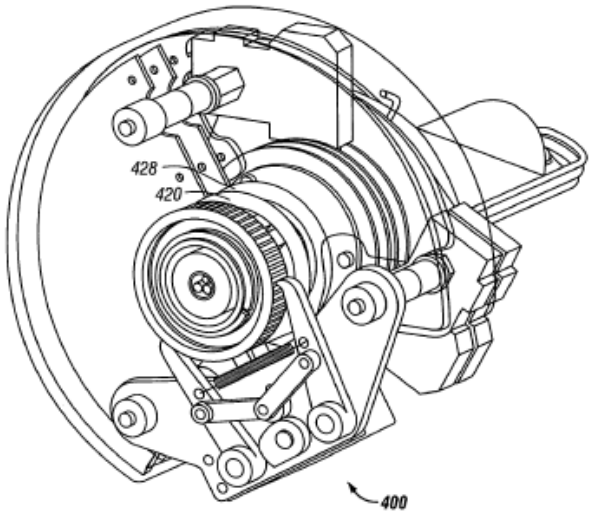


FIG. 4B

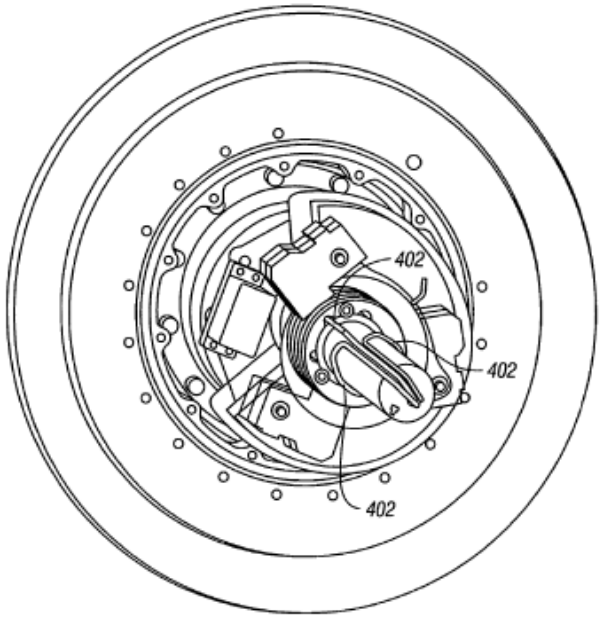
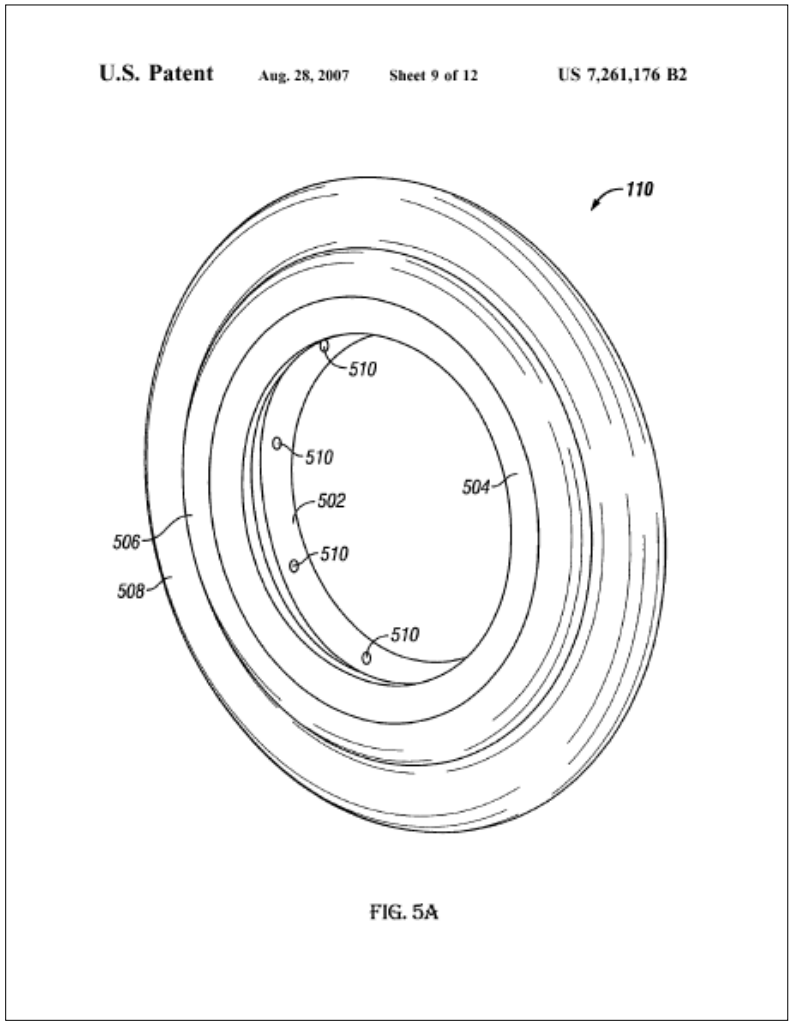
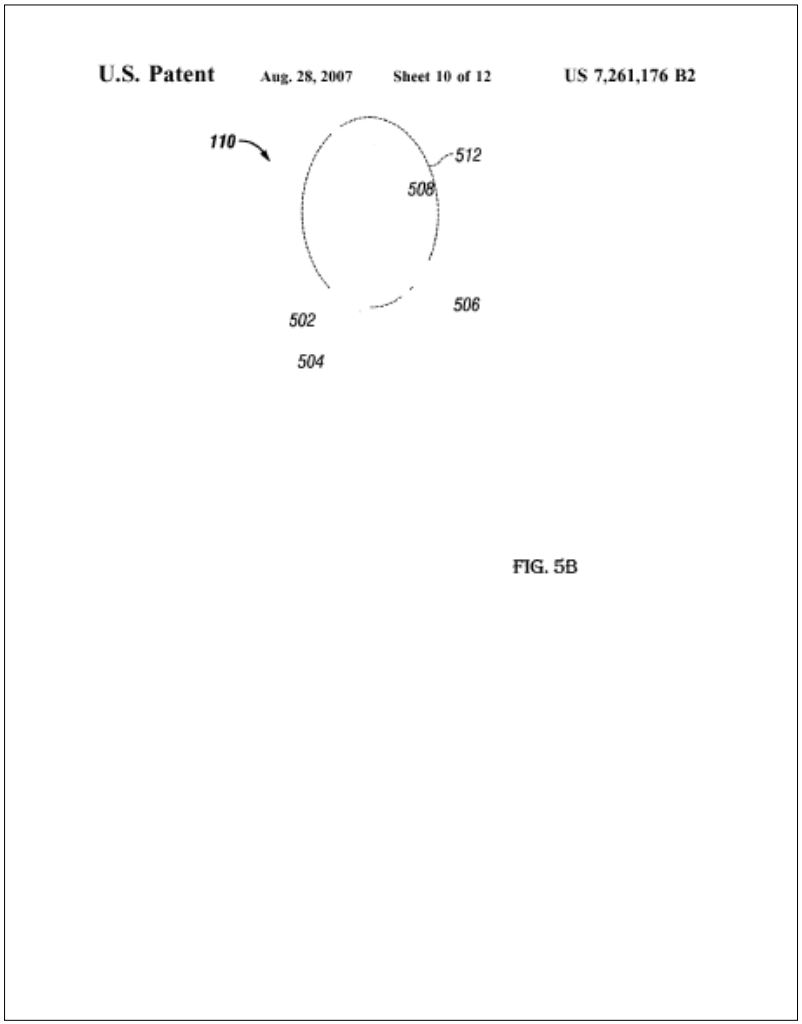


FIG. 4C

Patent No: US 7,261,176 B2





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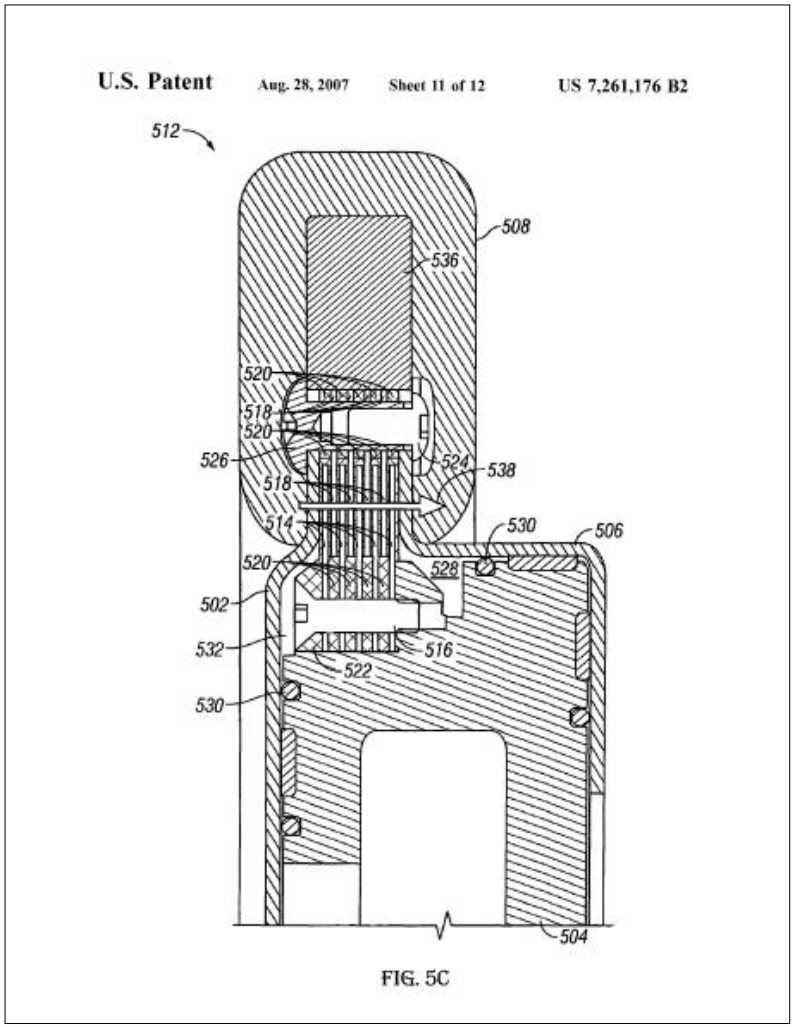

FIG. 5C

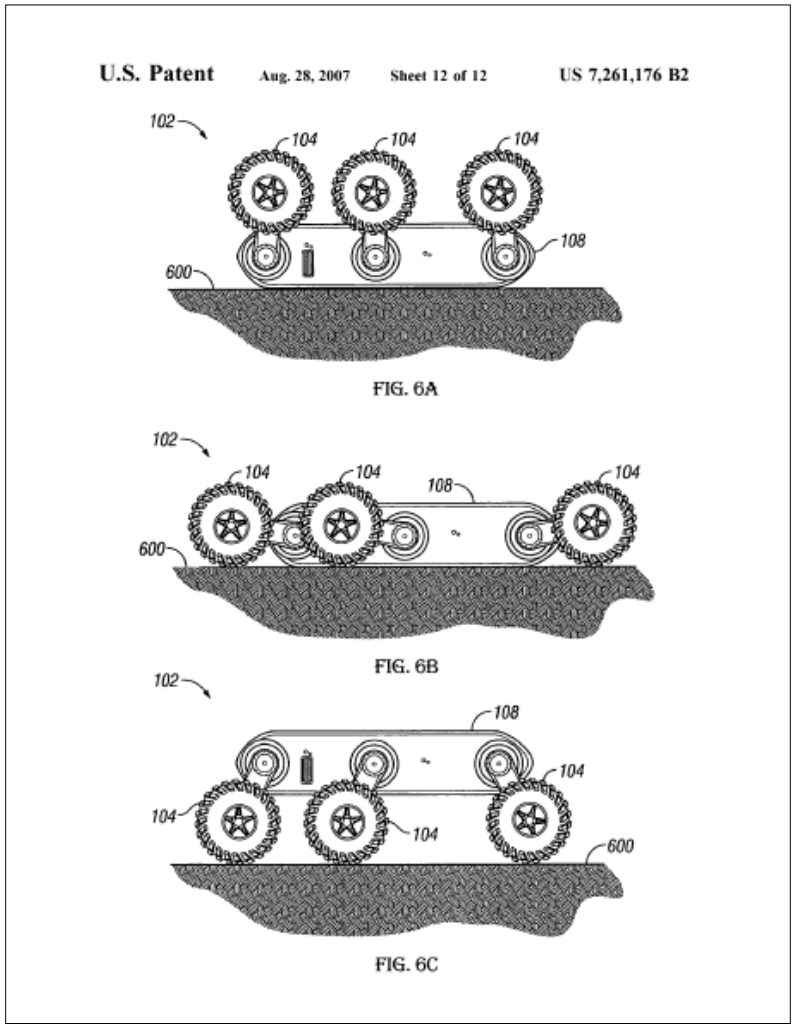

FIG. 6A

FIG. 6B

FIG. 6C

Patent No: US 7,261,176 B2

ARTICULATED VEHICLE SUSPENSION SYSTEM SHOULDER JOINT

BACKGROUND OF THE INVENTION

We claim the earlier effective filing date of co-pending U.S. Provisional Application Ser. No. 60/449,271, entitled "Unmanned Ground Vehicle," filed Feb. 21, 2003, in the name of Michael S. Beck, et al., for all common subject matter.

1. Field of the Invention

The present invention pertains to an articulated suspension system for use in a vehicle and, more particularly, to a shoulder joint for an articulated suspension system.

2. Description of the Related Art

One fundamental part of any ground vehicle is the suspension, or that part of the vehicle's undercarriage that absorbs and/or dampens perturbations in the surface being traversed. For instance, many passenger vehicles employ shock absorbers and leaf springs to help absorb perturbations and smooth the ride for the passengers. Environmental characteristics and conditions that cause such perturbations are generically referred to as "obstacles." Obstacles may be positive, e.g., a bump in the road, or negative, e.g., a hole or trench in the road. Vehicle suspensions systems are typically designed to handle both positive and negative obstacles within predetermined limits.

The design process for a suspension system, like any engineering design effort, involves numerous performance tradeoffs depending on many factors. For instance, a car and a truck, while both passenger vehicles, may be used for different purposes—namely, transporting people and cargo, respectively. Suspensions for cars and trucks are therefore designed differently, and it is common knowledge that stiffer truck suspensions do not provide as smooth a ride as do car suspensions.

For some classes of vehicles, suspension design is somewhat more difficult than for others because of intended operating conditions. Most passenger vehicles are designed for operation on relatively smooth, constant surfaces such that obstacle negotiation is not much of an issue. However, some vehicles are intended for much harsher environments. Exemplary of this class are military vehicles, which are typically designed to overcome extreme obstacles, and typically the more extreme the better.

The present invention is directed to resolving, or at least reducing, one or all of the problems mentioned above.

SUMMARY OF THE INVENTION

In a first aspect, the invention is a vehicle comprising a plurality of wheel assemblies; a plurality of rotating shoulder joints, each wheel assembly being mounted to a respective one of the shoulder joints and rotatable in a plane by the respective shoulder joint; and a chassis to which the shoulder joints are mounted.

In a second aspect, the invention is a shoulder joint for use in a vehicle suspension system, comprising: a housing to which a wheel assembly may be attached for in-plane rotation; a drive; and a transmission engaged with the housing and the drive to reduce the speed of the drive motor as it drives the housing.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be understood by reference to the following description taken in conjunction with the accompanying drawings, in which like reference numerals identify like elements, and in which:

FIG. **1** depicts a vehicle employing an articulated suspension system including a shoulder joint in accordance with the present invention;

FIG. **2**A–FIG. **2**B detail one particular embodiment of the shoulder joint of the suspension system in FIG. **1** in an assembled, side, sectioned, plan view and in an exploded view, respectively;

FIG. **3**A–FIG. **3**B depict a wheel assembly of the articulated suspension system including a wheel assembly, a link structure, and a shoulder joint in an assembled and an unassembled view, respectively.

FIG. **4**A–FIG. **4**C illustrate a locking mechanism, a plurality of encoders, and a plurality of slip rings for the shoulder joint of the embodiment in FIG. **2**A–FIG. **2**B;

FIG. **5**A and FIG. **5**C detail the magnetorheological rotary damper of the wheel assembly of FIG. **1**;

FIG. **6**A–FIG. **6**C illustrates the operation of the vehicle of FIG. **1** in an inverted position; and

FIG. **7** illustrates the operation of the vehicle of FIG. **1** operating at least partially submerged.

While the invention is susceptible to various modifications and alternative forms, the drawings illustrate specific embodiments herein described in detail by way of example. It should be understood, however, that the description herein of specific embodiments is not intended to limit the invention to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE INVENTION

Illustrative embodiments of the invention are described below. In the interest of clarity, not all features of an actual implementation are described in this specification. It will of course be appreciated that in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort, even if complex and time-consuming, would be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

Turning now to FIG. **1**, the present invention comprises a shoulder joint **100**, best shown in FIG. **2**A–FIG. **2**B, for use in an articulated suspension system. The articulated suspension system of the illustrated embodiment supports a vehicle **102**, shown in FIG. **1**, through a plurality of wheel assemblies **105**, shown best in FIG. **3**A–FIG. **3**B. Each wheel assembly **105** is mounted to a respective one of the shoulder joints **100** and is rotatable in a plane by the respective shoulder joint **100**. Each wheel assembly **105** includes, as is shown in FIG. **3**A–FIG. **3**B, a wheel **300**, a hub assembly **302**, and a link structure **304**. In the illustrated embodiment, the link structure **304** is a "suspension arm," and shall be hereinafter referred to as such. The present invention, however, is not so limited but, rather, may comprise any suitable link structure. The shoulder joints **100**, in concert, enable independent articulation of the suspension. The shoulder

joint **100** provides the high torque desirable for articulated arm movement and the rotary compliance for suspension isolation.

In addition to being the interface (structure, power, data pass thru, etc.), the shoulder joint **100** rotates in plane, preferably with a greater than a full revolution, with several revolutions desirable. This implies that the shoulder joint **100** rotates in plane via a motor/transmission package. Thus, the shoulder joint **100** comprises, in the embodiment illustrated in FIG. **2**A–FIG. **2**B, a drive **205**, harmonic drive **210**, planetary gear set **215**, slip clutch **220**, and torsion bar assembly **225** connected in series between the chassis **108** (shown in FIG. **1**) and the suspension arm **304** (shown in FIG. **3**A–FIG. **3**B). The planetary gear set **215** includes a sun gear **216** that engages a planetary gear **217** that, in turn, engages a ring gear **218** on the interior of the housing **226**. The torsion bar assembly **225** includes an inner torsion bar **229** and an outer torsion bar **231**. The inner torsion bar **229** includes on one end thereof a plurality of splines **233** that engage an end bell **228**. The inner torsion bar **229** is nested within the outer torsion bar **231**, and includes on the other end a plurality of splines **234** that engage the interior of an end **237** of the outer torsion bar **231**. The outer torsion bar **231** also includes a plurality of splines **239** that engages the slip clutch **220**.

The shoulder joint **100** also includes a housing **226** to which the suspension arm **304** is attached. More particularly, the housing **226** is retained on a shoulder spindle **223** on the sleeve bearings **221** and a ring gear **219**. The housing **226** is retained on the shoulder spindle **223** by a thrust retainer **235** secured by a plurality of fasteners **227**. Note that, in the illustrated embodiment, the suspension arm **304** is fabricated integral to the housing **226**, i.e., the housing **226** and the suspension arm **304** structurally form a single part. The housing **226** includes a plurality of bearings (not shown) on the inside thereof. The bearings interact with the planetary gear set **215** to rotate the housing **226** and, hence, the suspension arm **304**. The shoulder joint **100** is capped, in the illustrated embodiment, by an end bell **228** to transmit torque between the torsion bar assembly **225** and the suspension arm **304** as well as to help protect the shoulder joint **100** from damage and debris.

Still referring to FIG. **2**A–FIG. **2**B, the drive **205** is, in the illustrated embodiment, an electric motor including a rotor **225** and a stator **230**. The drive **205** can be co-aligned along the same axis of the shoulder **100**, as in the illustrated embodiment. Alternatively, the drive **205** can be offset (not shown) and connected to the axis of actuation through a transmission, e.g., chain-driven. The drive **205** does not have to be electric, and can be a hydraulic, pneumatic, or a hybrid motor system. The drive **205** may comprise any type of drive known to the art, for example, a direct-drive motor, a servo motor, a motor-driven gearbox, an engine-driven gearbox, a rotary actuator, or the like. The drives **205** may be mechanically independent drives (i.e., not mechanically linked to each other). The shoulder motors **205** may be components of a power transmission system (e.g., a gearbox with clutched power take-offs) capable of operating each of the shoulder motors **205** independently.

The harmonic drive **210** and planetary gear set **215** implement a mechanical transmission. Some embodiments may also include a spur gear box, a traction drive, etc., in implementing a mechanical transmission. Mechanical transmissions have three primary applications in machine design: speed reduction, transferring power from one location to another, and converting motion from prismatic to rotary or vice versa. The shoulder joint **100** employs the mechanical

transmission for speed reduction, which proportionally increases torque to rotate the wheel assembly **104**. For most moving parts, bearings are used to reduce friction and typically are designed in pairs to protect against radial, thrust, and moment loading on the actuator. Since the bearings transfer loads, the structure or housing of the shoulder actuator should be designed adequately to preclude structural failures and deflections. The harmonic drive **210** provides a first speed reduction and the planetary gear set **215** provides a second speed reduction.

The motor **205** and the transmission (i.e., the harmonic drive **210** and planetary gear set **215**) may be considered the heart of the actuator for the shoulder joint **100**. The remaining components facilitate the operation of the motor **205** and the transmission and may be omitted in various alternative embodiments (not shown). A clutch assembly (i.e., the slip clutch **220**) may be integrated such that the linked wheel assembly **104** may be disengaged (not powered or controlled) where positioning is passive based only on gravity effects. The slip clutch **220** also limits the torque through the drive system and is capable of dissipating energy to prevent damage. Similarly, a torsion assembly (i.e., the torsion bar assembly **225**) may be used to control the twist properties of the shoulder joint **100** by actively engaging different effective torsion bar lengths.

Thus, some embodiments may include the slip clutch **220** and/or the torsion bar assembly **225**, whereas others may omit them. Furthermore, recent actuator development has shown the tendency to mount the motor servo-controller electronics close to the motor. If the drive **205** is brushless, the commutation sensor (not shown) and drive electronics (also not shown) could also be packaged in the actuator assembly. Thus, in some embodiments, the motor servo-controller electronics may comprise a portion of the shoulder joint **100**. In the illustrated embodiment, the commutation sensors (not shown) are located in the stator.

As is shown in FIG. **4**A–FIG. **4**B, a small spring applied, electrically released locking mechanism **400** prevents rotation of the motor so that power is not required when the vehicle **102** is static. The locking mechanism **400** does not require power to maintain its state. Power is only required to change states; that is to lock or unlock. Furthermore, no state change will occur after power failure. If the locking mechanism **400** is locked, it will remain locked in the event power fails. If the locking mechanism **400** is unlocked, it will remain unlocked upon loss of power.

More particularly, the locking mechanism **400** of the illustrated embodiment includes a pair of pawls **402** that interact with a toothed lock ring **404** on the motor shaft **406** of the drive **205**. A spring **408**, or some other biasing means, biases the pawls **402** to close on the lock ring **404** when the cam **410** is positioned by the servo-motor **409** to allow for movement of the driver **412** and linkage. To unlock the locking mechanism **400**, the servo-motor **409** actuates the cam **410** to operate against driver **412** and open the pawls **402** away from the lock ring **404**. Note that the pawls **402**, the servo-motor **409**, cam **410**, and driver **412** are all mounted to a mounting plate **414** that is affixed to the chassis **108** (shown in FIG. **1**). When the lock is engaged, no power is required. However, in some alternative embodiments, a spring applied brake may be used to facilitate locking the actuator shaft **406**. In these embodiments, the locking mechanism **400** will still lock the shoulder joint **100** on power failure, but will consume power, when unlocked, as long as power is available.

FIG. **4**B also illustrates a plurality of encoders. To know the absolute position of the shoulder joint **100**, a position

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sensor such as a resolver, encoder, or potentiometer is used to measure for this information. The illustrated embodiment employs an arm position encoder **428** and a torsion bar twist encoder **420** to acquire data regarding the position of the arm **304** and the twist on the torsion bar assembly **225**, respectively. From this data, a control system (not shown) can determine the arm speed, arm reaction torque, and estimated suspension load for the shoulder joint **100**. Note that some embodiments may integrate a tachometer and calculate the same position data using simple calculus.

Returning to FIG. **2**A–FIG. **2**B, the drive **205**, sensors (not shown), electronics (also not shown), and locking mechanism **400** all require power. Power is provided by the vehicle **102** (shown in FIG. **1**) to each shoulder joint **100** and moreover, some power is passed through from the vehicle chassis **108** through the shoulder joint **100** and to the driven-hub **302** to drive the wheel **300**. In addition to power, data signals follow the same path. To pass power and data signals over the rotary shoulder joints **100**, a plurality of slip rings **432**, shown in FIG. **4**C are used. The supply of power should be isolated from data due to noise issues, and the illustrated embodiment employs separate slip rings to transmit power and data. Note that conductors (not shown) are attached to each side of the slip rings **432** with each side rotatably in contact with each other to maintain continuity.

Other options include the integration of a rotary damper to add suspension characteristics. Primary suspension damping for the vehicle **102** in FIG. **1** is provided in the illustrated embodiment by a controllable, magnetorheological ("MR") fluid based, rotary damper **110** connecting the suspension arm **304** to the chassis **108**, mounted in parallel with the shoulder joint **100**. The rotary MR damper **110**, first shown in FIG. **1** but best shown in FIG. **5**A–FIG. **5**H at each suspension arm **304** provides actively variable damping torque controlled by a central computer (not shown). This control allows for optimized vehicle dynamics, improved traction, articulation, impact absorption and sensor stabilization. The system improves obstacle negotiation by enabling the shoulder joints **100** to be selectively locked, improving suspension arm **304** position control. Damping is controllable via a magnetically sensitive fluid. The fluid shear stress is a function of the magnetic flux density. The flux is generated by an integrated electromagnet that is capable of varying the resultant damping torque in real time.

The MR rotary damper **110** controls the applied torque on the shoulder joint **100** during all of the vehicle operational modes. It provides the muscle to the vehicle **102** for absorbing impacts, damping the suspension and accurately controlling the position of the joint. The MR rotary damper **110** increases traction and decreases the transmission of vertical accelerations into the chassis **108**. The MR damper **110**'s ability to change damping force in real-time via software control maintains suspension performance over all operating conditions, such as changing wheel loads, varying wheel positions, and varying the vehicle **102** center of gravity.

Turning now to FIG. **5**A–FIG. **5**C, the rotary damper **110** includes an inner housing **502**, a rotor **504**, an outer housing **506**, and a segmented flux housing **508**. The inner housing **502**, outer housing **506**, and segmented flux housing **508** are fabricated from a "soft magnetic" material (a material with magnetic permeability much larger than that of free space), e.g., mild steel. The rotor **504** is made from a "nonmagnetic" material (a material with magnetic permeability close to that of free space), e.g., aluminum. In one embodiment, the segmented flux housing **508** is fabricated from a high performance magnetic core laminating material commercially available under the trademark HIPERCO 50® from:

Carpenter Technology Corporation

P.O. Box 14662

Reading, Pa. 19612-4662

U.S.A.

Phone: (610) 208-2000

FAX: (610) 208-3716

However, other suitable, commercially available soft magnetic materials, such as mild steel, may be used.

The rotary damper **110** is affixed to, in this particular embodiment, a chassis **108** by fasteners (not shown) through a plurality of mounting holes **510** of the inner housing **502**. The rotor **504** is made to rotate with the pivoting element (not shown) with the use of splines or drive dogs (also not shown). Note that the rotary damper **110** may be affixed to the suspension arm **304** and the chassis **108** in any suitable manner known to the art. The rotary damper **110** damps the rotary movement of the arm pivot relative to the chassis **108** in a manner more fully explained below.

Referring to FIG. **5**C, pluralities of rotor plates **514**, separated by magnetic insulators **520**, are affixed to the rotor **504** by, in this particular embodiment, a fastener **516** screwed into the rotor plate support **522** of the rotor **504**. A plurality of housing plates **518**, also separated by magnetic insulators **520**, are affixed to an assembly of the inner housing **502** and outer housing **506**, in this embodiment, by a fastener **524** in a barrel nut **526**. Note that the assembled rotor plates **514** and the assembled housing plates **518** are interleaved with each other. The number of rotor plates **514** and housing plates **518** is not material to the practice of the invention.

The rotor plates **514** and the housing plates **518** are fabricated from a soft magnetic material having a high magnetic permeability, e.g., mild steel. The magnetic insulators **520**, the fasteners **516**, **524**, and the barrel nut **526** are fabricated from nonmagnetic materials, e.g., aluminum or annealed austenitic stainless steel. The nonmagnetic fasteners can be either threaded or permanent, e.g., solid rivets. The rotor plates **514** and the housing plates **518** are, in this particular embodiment, disc-shaped. However, other geometries may be used in alternative embodiments and the invention does not require that the rotor plates **514** and the housing plates **518** have the same geometry.

Still referring to FIG. **5**D, the assembled inner housing **502**, rotor **504**, and outer housing **506** define a chamber **528**. A plurality of O-rings **530** provide a fluid seal for the chamber **528** against the rotation of the rotor **504** relative to the assembled inner housing **502** and outer housing **506**. An MR fluid **532** is contained in the chamber **528** and resides in the interleave of the rotor plates **514** and the housing plates **518** previously described above. In one particular embodiment, the MR fluid **532** is MRF132AD, commercially available from:

Lord Corporation

Materials Division

406 Gregson Drive

P.O. Box 8012

Cary, N.C. 27512-8012

U.S.A

Ph: 919/469-2500

FAX: 919/481-0349

However, other commercially available MR fluids may also be used.

The segmented flux housing **508** contains, in the illustrated embodiment, a coil **536**, the segmented flux housing **508** and coil **536** together comprising an electromagnet. The coil **536**, when powered, generates a magnetic flux in a direction transverse to the orientation of the rotor plates **514** and the housing plates **518**, as represented by the arrows **538**. Alternatively, a permanent magnetic **540** could be incorporated into the flux housing **508** to bias the magnetic flux **538**. The coil **536** drives the magnetic flux through the MR fluid **532** and across the faces of the rotor plates **514** and the housing plates **518**. The sign of the magnetic flux is not material to the practice of the invention.

The magnetic flux **538** aligns the magnetic particles (not shown) suspended in the MR fluid **532** in the direction of the magnetic flux **538**. This magnetic alignment of the fluid particles increases the shear strength of the MR fluid **532**, which resists motion between the rotor plates **514** and the housing plates **518**. When the magnetic flux is removed, the suspended magnetic particles return to their unaligned orientation, thereby decreasing or removing the concomitant force retarding the movement of the rotor plates **514**. Note that it will generally be desirable to ensure a full supply of the MR fluid **532**. Some embodiments may therefore include some mechanism for accomplishing this. For instance, some embodiments may include a small fluid reservoir to hold an extra supply of the MR fluid **532** to compensate for leakage and a compressible medium for expansion of the MR fluid **532**.

Returning to the illustrated embodiment, the control system commands an electrical current to be supplied to the coil **536**. This electric current then creates the magnetic flux **538** and the rotary damper **110** resists relative motion between the housings **502**, **506** and the rotor **504**. Depending on the geometry of the rotary damper **110** and the materials of its construction, there is a relationship between the electric current, the relative angular velocity between the housings **502**, **506** and the rotor **504**, and the resistive torque created by the rotary damper **110**. In general this resistive torque created by the rotary damper **110** increases with the relative angular motion between the housings **502**, **506** and the rotor **504** and larger magnetic flux density through the fluid **532** as generated by the coil electric current.

Unfortunately, the MR rotary damper **110** tends to have a high inductance. This problem can be mitigated with the use of high control voltages which allow for high rates of change in damper current (di/dt), although this may lead to increased power demands and higher levels of inefficiency depending on the design and the software control driving the rotary damper **110**. Another technique, which may improve the bandwidth and efficiency of the MR rotary damper **110**, uses multiple coil windings. One such system could use two coil windings; one high inductance, slow coil with a high number of turns of small diameter wire and a second low inductance, fast coil with a low number of turns of larger diameter wire. The slow coil would could be used to bias the rotary damper **110** while the fast coil could be used to control around this bias. However, the two coil windings may be highly coupled due to the mutual inductance between them in some implementations, which would be undesirable.

Returning to FIG. **4**B, the vehicle **102** employs a suspension arm positions encoder **428** for each suspension arm **304**. The arm position encoders **428** measure the relative position of the respective suspension arms **304** to the chassis **108**. In various alternative embodiments, the arm position encoders may be implemented as optical encoders, resolvers, or potentiometers. From this measurement a control system **114**, shown in FIG. **1**, can also determine the relative angular velocity of the suspension arms **304**. As a simple damper, the MR rotary damper **110** would be commanded to produce a torque proportional to and against the suspension arm angular velocity.

More advanced control algorithms could command the MR rotary damper **110** to produce a resistive torque related to other variables such as: the positions of the suspension arms **304** relative to the chassis **108**, the vertical acceleration on the chassis **108**, the vehicle roll and pitch angles and angular rates, and the wheel hub motor torques (these would be determined by the vehicle control for controlling vehicle speed and turning). The illustrated embodiments also employ an inertial sensor **116** to help measure some of these variables. In various alternative embodiments, the inertial sensor can be implanted with gyroscopes (e.g., fiber optic, ring laser, mechanical) angular rate sensors, tilt sensors, and accelerometers.

Returning to FIG. **3**A–FIG. **3**B, the suspension arm **304** has a hollow construction that is structurally efficient and provides for mounting of motors, controller, wiring, etc., within the suspension arm **304**. The suspension arm **304** is subject to multidirectional bending, shocks and debris impact/wear. The suspension arm **304** is, in the illustrated embodiment, made of ceramic (alumina) fiber reinforced aluminum alloy, i.e., the suspension arm **304** comprises a "metal matrix composite" material. This material provides for high thermal conductivity, high specific stiffness, high specific strength, good abrasion resistance and long fatigue life. Some embodiments may include ceramic particulate reinforcement in at least selected portions. The suspension arm **304** therefore also provides mechanical protection and heat sinking for various components that may mounted on or in the suspension arm **304**. Note that the length of the suspension arm **304** may be varied depending on the implementation.

With respect to the wheel assemblies **105**, each of the wheels **300** may comprise a pneumatic, semi-pneumatic, or solid tire. Vibrations or other undesirable motions induced into the vehicle **102** by rough terrain over which the vehicle **102** travels may be dampened by the mechanical compliance of the wheels **300**. In other words, the wheels **300** deform to absorb the shock forces resulting from traveling over rough terrain. In addition, such shock forces may be absorbed by one or more shock absorbers, spring elements, and/or dampers, such as those known in the art, that are incorporated in the suspension arms **304**. However, the illustrated embodiment employs the MR rotary damper **110**, most clearly illustrated in FIG. **5**A–FIG. **5**H, and discussed above.

In the illustrated embodiment, the hub assemblies **302** include a drive mechanism comprising a hub drive motor (not shown) and a two-speed shifting in-hub transmission (also not shown) embedded in the hub of a wheel to allow for high and low speed operation with a hub drive motor. The hub assembly **302** is a tightly integrated package that combines a Variable Reluctance Motor ("VRM"), two-speed

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gear reduction, motor support frame and hub spindle. Mounted at the end of the suspension arm, it encapsulates the in-hub drive motor and provides support for wheel/tire loads and is waterproof.

Thus, as is shown in FIG. **1**, the suspension system actually comprises a plurality of wheel assemblies **105**, each rotated by a shoulder joint **100** and whose rotation is damped by a rotary magnetorheological ("MR") damper **110**. The rotary magnetorheological ("MR") damper **110**, facilitated by real time damping control, is mounted coaxially with the suspension arm **304** of the wheel assembly **105**. Each wheel assembly **105** has a compliant rotary suspension with controllable damper **110** to absorb impacts and provide for sensor stability.

Still referring to FIG. **1**, each of the wheel assemblies **105** is independently rotatably coupled with the chassis **108** by its shoulder joint **100**. When a shoulder joint **100** is driven, the assembly **105** coupled therewith is rotated with respect to the chassis **108**. Each of the wheel assemblies **105** may be independently moved by the respective drive **205** of its respective shoulder joint **100** to any desired rotational position with respect to the chassis **108** at a chosen speed. For example, each of the wheel assemblies **105** may be moved from a starting rotational position (or a "zero" or "home" rotational position) to a rotational position of 45° clockwise, to a rotational position of 180° counterclockwise, or to any other desired rotational position.

FIG. **6**A–FIG. **6**C illustrates the operation of the vehicle **102** of FIG. **1** in an inverted position. The slope negotiation capabilities of the vehicle **102** are dependant solely on available traction, not on rollover like many manned vehicles. Shifting the wheels **120** relative to the center of gravity (to evenly load the wheels **120**) accommodates steep side slopes and ascents/descents. However, even if the vehicle **102** rolls over, there is only a notional "top" to this vehicle **102** design; the full, 360° rotation of the wheel assemblies **105** about the shoulder joint **100** enables vehicle **102** reconfiguration for inverted operations in the event of a tumble or roll, thus alleviating the need for self-righting.

The vehicle **102** may encounter terrain so rugged or sloped that the vehicle **102** is turned over, as shown in FIG. **6**A. As shown in FIG. **6**B, the vehicle **102** may continue to traverse across the surface **600** by rotating the wheel assemblies **104** such that the wheels **300** contact the surface **600**. As shown in FIG. **6**C, the wheel assemblies **104** may then be further rotated to lift the chassis **108** from the surface **600**, and the vehicle **102** may continue to traverse across the surface **600**.

FIG. **7** illustrates the operation of the vehicle **102** partially submerged in body of water **700**. The shoulder joint **100**, hub assembly **302**, and rotary damper **110** are all sealed against water intrusion, thereby permitting operation of the vehicle **102** partially or wholly submerged. Techniques for sealing such structures are know to the art. For instance, fully submersible land vehicles employ snorkels (not shown) for delivering air to internal combustion engines when under water. Any such suitable techniques may be used.

The articulated suspension system of the illustrated embodiment employs six wheel assembly **105**/shoulder joint **100** combinations (not all shown) positioned symmetrically about the chassis **108** in collinear pairs. However, this is not necessary to the practice of the invention. The precise number of wheel assemblies **105** and shoulder joints **100** will be implementation specific. The shoulder joints **100** need not be positioned about the chassis **108** symmetrically or in collinear pairs. Similarly, although the shoulder joints **100** are capable of fully rotating the wheel assemblies **105** in the illustrated embodiment, this is not necessary to the practice of the invention, either. Some embodiments may employ less than full rotation.

This concludes the detailed description. The particular embodiments disclosed above are illustrative only, as the invention may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. For instance, in some embodiments, the shoulder joint **100** may be prismatic to allow an additional degree of freedom in movement. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the invention. Accordingly, the protection sought herein is as set forth in the claims below.

What is claimed:

1. A shoulder joint for use in a vehicle suspension system, comprising:
- a housing to which a wheel assembly may be attached for in-plane rotation;
- a drive; and
- a transmission engaged with the housing and the drive to reduce the speed of the drive as it drives the housing, the transmission including:
  - a harmonic drive engaged with the shoulder drive and capable of reducing the speed of the shoulder drive; and
  - a planetary gearset capable of further reducing the speed of the shoulder drive and engaging the housing to drive it.

2. The shoulder joint of claim **1**, wherein the shoulder drive is co-aligned with the axis of the shoulder joint.

3. The shoulder joint of claim **1**, wherein the shoulder drive is offset from the axis of the shoulder joint.

4. The shoulder joint of claim **1**, wherein the shoulder drive comprises one of a direct-shoulder drive, a servo motor, a motor-driven gearbox, an engine-driven gearbox, and a rotary actuator.

5. The shoulder joint of claim **1**, further comprising at least one of:
- a slip clutch between the planetary gearset and the housing to disengage the housing from the drive; and
- a spring preloading the planetary gearset and the harmonic drive.

6. The shoulder joint of claim **5**, wherein the spring comprises a torsion bar assembly.

7. The shoulder joint of claim **1**, further comprising a locking mechanism.

8. The shoulder joint of claim **7**, wherein the locking mechanism comprises a small spring applied, electrically released locking mechanism.

9. The shoulder joint of claim **1**, further comprising means for ascertaining the absolute position of the shoulder joint.

10. The shoulder joint of claim **9**, wherein the ascertaining means comprises at least one of a resolver, an encoder, or a potentiometer.

11. The shoulder joint of claim **9**, wherein the ascertaining means comprises at least one of an arm position encoder and a torsion bar twist encoder.

12. The shoulder joint of claim **1**, further comprising a plurality of slip rings through which signals may be transmitted.

13. An integrated shoulder joint, comprising:
- a torsion bar;
- a shoulder drive;
- a harmonic drive engaged with the shoulder drive and capable of reducing the speed of the shoulder drive and preloaded by the torsion bar;
- a slip clutch capable of disengaging the harmonic drive from the shoulder drive; and
- a plurality of slip rings through which signals can be sent through the integrated shoulder joint.

14. The shoulder joint of claim **13**, wherein the slip clutch limits the torque through a drive system of which the shoulder joint comprises a portion.

15. The shoulder joint of claim **14**, wherein the slip clutch is capable of dissipating energy to prevent damage.

16. The shoulder joint of claim **13**, wherein the slip clutch is capable of dissipating energy to prevent damage.

17. The shoulder joint of claim **13**, further comprising locking mechanism capable of preventing rotation of the motor.

18. The shoulder joint of claim **17**, wherein the locking mechanism is applied by a biasing means.

19. The shoulder joint of claim **18**, wherein the biasing means comprises a spring.

20. The shoulder joint of claim **18**, wherein the locking mechanism is electrically released.

21. The shoulder joint of claim **13**, wherein the shoulder joint comprises a prismatic joint.

22. The shoulder joint of claim **13**, wherein the shoulder joint offers multiple degrees of freedom of movement.

* * * * *

IP Summary

- Every new idea has elements that are purely new and also has elements that already existed
- IP refers to the bundle of legal rights that arise from the creative genius of the human mind
- Four types of IP: property rights, patents, trademarks, copyrights
- A patent is used to protect the intellectual property rights associated with the design of a product or process

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