Abstract:
The drive train includes a drive component, a driven component and a tolerance ring drivingly connecting the drive and driven components. The tolerance ring is rotationally fixed to one component and frictionally engaged with the other component. The components may be vehicle, machinery or equipment components such as a pulley, a sheave, a gear, a bushing, a coupling, a universal joint, an axle shaft, a driveshaft, a bearing, or a wheel.
CROSS REFERENCE TO RELATED APPLICATIONS

FIELD OF THE INVENTION
[0002] The present invention generally relates to torque limiting systems, and more specifically to torque transfer and torque limiting devices and their application to power transmission assemblies.

BACKGROUND OF THE INVENTION
[0003] Torque limiting devices can protect mechanical devices from damage by mechanical overload and can be used as torque transferring and limiting devices in various assemblies. Torque limiting devices protect rotary elements and their attendant components from damage which can be caused by torque spikes and mechanical overload. Torque limiting devices decouple or frictionally limit the torque to be transferred when a predetermined torque value is exceeded. Basic torque limiters are well known in the art and simple in their function. However, some torque limiters are complex, expensive, heavy, bulky, and may require stopping and resetting, and therefore are not suited for all applications.
SUMMARY OF THE INVENTION

[0004] The present invention is a torque-limiting assembly with a tolerance ring that frictionally connects a power source to a driving or driven component in a drive train. The components can be a pulley, sheave, gear, bushing, coupling, universal joint, axle shaft, driveshaft, bearing, differential or road wheel. The tolerance ring is rotationally fixed to one of the drive or driven components and frictionally engaged with the other component to provide a torque limiting driving connection. The mechanically locked tolerance ring is positioned between a power source and a driven device as part of a power transfer assembly. One or more torque limiting assemblies can be used in multiple locations in a single drive train.

[0005] The present invention provides increased durability by alleviating fatigue and overload damage due to shock, impact loading, directional changes and torque overload. The present invention may be used to prevent damage from mechanical overload by limiting torque transfer to a predetermined value. In operation, when drive train overloading causes the level of transmitted torque to exceed a predetermined torque limit, there is relative motion between the driving and driven components of the drive train. When the input torque falls to a level below that of the torque limit, the relative motion stops and torque transmission without backlash resumes.

[0006] The present invention provides a torque transfer and limiting drive train that is simple, compact, durable, light, versatile, scalable and cost effective. The drive train can be used to provide a range of torque transfer and limitation characteristics. The drive train includes a mechanically locked tolerance ring to provide previously unavailable durability and consistent ranges of torque transfer and limitation values.
[0007] The present invention can be used in numerous industrial and vehicle applications to transfer torque from a power source through drive shafts, including steering column shafts, pulleys, universal joints, including constant velocity joints, axles or other devices to road wheels, rubber or metal tracks, aircraft vehicle propellers, turbine blades, marine vehicle propellers or jet drives, mechanical devices such as drilling, milling, cutting and grinding machinery, hand tools, including screw drivers, socket wrenches, and startup clutches for accelerating large masses where short-term peak torques must be limited without interrupting work. The present invention can be produced in a compact annular design that allows placement in or around many existing configurations of pulleys, drive shafts, half shafts, axles, constant velocity joints, driving shafts, gears and differentials.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Figure 1 is an exploded view of a prior art tolerance ring assembly.

[0009] Figure 2 is a perspective view of the tolerance ring of Figure 1.

[0010] Figures 3-5 are typical performance graphs for tolerance rings of the type shown in Figure 1.

[0011] Figure 6 is an exploded view of a tolerance ring assembly of the present invention.
Figures 7 and 8 are cross-sectional views of the assembled tolerance ring assembly of Figure 6.

Figure 9 is a graph of test results of a tolerance ring of the present invention.

Figure 10 is a graph showing a torque impulse transmitted by a typical rotating assembly without a tolerance ring or other torque limiting device.

Figure 11 is a graph showing a torque impulse transmitted by a typical tolerance ring of the present invention.

Figure 12 is a graph of a typical SN fatigue curve.

Figure 13 is an exploded view of a constant velocity joint with a torque limiting device of the present invention.

Figure 14 is a view of the assembled constant velocity joint of Figure 13.

Figure 15 is a view of the assembled constant velocity joint of Figure 16.
Figure 16 is an exploded view of an alternative constant velocity joint assembly with a torque limiting device of the present invention.

Figure 17 is an exploded cross-sectional view of a torque limiting wheel hub of the present invention.

Figure 18 is a cross-sectional view of the assembled torque limiting wheel hub of Figure 17.

Figure 19 is a cross-sectional exploded view of a torque limiting axle shaft.

Figure 20 is a cross-sectional view of the assembled torque limiting axle shaft of Figure 19.

Figure 21 is a plan view of the assembled torque limiting axle shaft of Figure 19.

Figure 22 is a plan view of a torque limiting swing-axle shaft.

Figure 23 is a plan view of an alternative torque-limiting axle shaft.

Figure 24 is a plan view of a torque-limiting common propeller type drive shaft.
[0029] Figure 25 is a cross-sectional view of a torque-limiting differential of the present invention.

[0030] Figures 26A is an exploded view of the side gear and tolerance ring of Figure 25.

[0031] Figure 26B is an exploded view of an alternative differential side gear and tolerance ring for the differential of Figure 25.

[0032] Figure 27A is a cross-sectional view of a manually adjustable torque-limiting device of the present invention.

[0033] Figure 27B is a cross-sectional view of the manually adjustable torque-limiting device of Figure 27A within a housing.

[0034] Figure 27C is a cross-sectional view of an alternative manually adjustable torque-limiting device of the present invention.

[0035] Figure 27D is a cross-sectional view of the manually adjustable torque-limiting device of Figure 278C within a housing.
Figure 28 is an exploded view of an automatically adjustable torque-limiting device of the present invention.

Figure 29 is a plan view of the assembled device of Figure 28.

Figures 30, 31, 32, and 33 are schematic diagrams of drive train applications of the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to Figure 1, a prior art externally corrugated tolerance ring assembly A, includes an annular tolerance ring 1, an annular external element in the form of a housing or tubular shaft 2 having a smooth cylindrical internal surface, and an annular internal component in the form of a shaft 3 having a smooth cylindrical external surface. Referring to Figure 2, the tolerance ring 1 has a corrugated side 10 and a smooth side 20. The tolerance ring 1 is generally made of resilient metal such as spring steel, with corrugations 12 having peaks 16. The corrugations are circumferentially spaced between valleys 17 by a pitch arc or distance 18. The corrugations may project radially outwardly as shown or radially inwardly, and may be arranged in a single or multiple circumferential rows. The corrugations can be of uniform or varying height, shape and pitch, and are bordered by pair of smooth side rims 14. In the assembly A, the corrugations are compressed to provide limited frictional torque transmitting capacity.

The tolerance ring 1 is commonly produced by running a strip of metal through intermeshing rotary dies. The strip is then cut to length and curled into a ring shape with a gap or split 15. Many tolerance rings are made for specific applications and can be designed to have substantial torque-transfer ratings.
Tolerance rings, have been proven to be capable of providing axial retention, radial loading, torque transfer and limitation between mating cylindrical components such as a housing and a shaft.

[0041] When a tolerance ring is compressed between mating cylindrical components each corrugation acts as a spring, resulting in a frictional connection between the components. The frictional torque capacity of the tolerance ring is the resultant force of all the corrugations and their coefficients of friction with the mating components. If the compression of the corrugations remain within their elastic limits, there is a linear relationship between compression and frictional torque. Rotational drive applied to either the outer or inner component will transmit torque to the other component. If the input torque is higher than a predetermined threshold, the components will rotate relative to each other, i.e. one will slip. When slippage occurs, the corrugated side of the tolerance ring can slip before the smooth side because the contact or pressure area is smaller. When the described slippage occurs, the corrugations and the slipping surface that they engage can become damaged because of the many small high-pressure areas rotating against a surface.

[0042] Graphs showing the relationship between corrugation compression $C$ and torque transfer $T$ are shown in Figures 3-5. Figure 3 illustrates that the linear relationship between compression and torque ceases when the ring is compressed beyond its elastic limits, e.g., it is plastically deformed. Figure 4 illustrates that torque transfer values decrease and may become unstable between the installed torque-value, itv, and the working torque-values, wtv, because the corrugations slip erratically against and may wear the contacted component. Figure 5 illustrates the effects of long-term repeated torque-slip and the loss of compression and torque transfer.
Referring to Figures 6, 7 and 8, a tolerance ring assembly 30 of the present invention includes a tolerance ring 31, an annular external element in the form of a tubular shaft or housing 32, and an annular internal element in the form of a shaft 33. The internal and external elements may be components of various vehicles, machines or equipment identified herein, such as pulleys, sheaves, gears, bushings, couplings, universal joints, axle shafts, drive shafts, bearings, or wheels. The ring, housing and shaft are coaxial and rotatable around axis R. The radially inner surface of the housing 32 includes generally axially extending grooves 34, each groove corresponding to a tolerance ring corrugation 35 to provide mechanical locking between the tubular shaft 32 and the tolerance ring 31. The tolerance ring 31 is compressed between the inner and outer components such that the spring force provides a predetermined frictional force to drivingly engage the components up to a predetermined torque limit. The tolerance ring assembly 30 predictably and reliably maintains its predetermined constant torque slip value because the amount of compression of the corrugation is maintained within the elastic limits of the ring material and because wear of the corrugations is limited. The tolerance ring assembly 30, properly designed and lubricated, can provide a predetermined constant torque slip value and a very long service life under a very wide range of bi-directional rotational conditions.

**Test Results**

Figure 9 illustrates long term testing of a tolerance ring of the present invention through typical working cycles. The test was run with an off-the-shelf tolerance ring constructed of Type 301 stainless steel. The shaft was an automobile stub axle of unknown metallurgy. Neither the tolerance ring nor the shaft was in any way optimized for wear. It can be seen that long term working torque value wtv is extremely stable. The graph shows a test with an initial torque value itv of 39 ft-lbs, and an average wtv of 31 ft-lbs (±2 ft-lbs depending on oil
temperature) for a total of 165,000 revolutions before testing was stopped. The shaft was rotated in randomized intervals of 1 to 8 seconds at a rotational speed of 25 rpm. Since a torque limiting driveline component would see very few rotations at higher torque transfer values and speeds, it is clear that with optimization, the present invention could be designed to have a very long service life.

Torque-Limiting Component Concept

[0045] Because many standard drive train components are capable of transmitting torque sufficient to cause drive train damage, power train components are designed to withstand high impulse loads. In automotive vehicle applications, high transient torsional loads can be generated in situations when a tire is unloaded and allowed to spin, and suddenly brought back into contact with the road. Another a high torsional load scenario occurs when a tire under high power encounters a road feature that allows the tire to transmit more torque than it normally could from its traction capacity. For instance, if a spinning tire under high power falls into a pot hole, the rotational kinetic energy combined with the abnormal increase in traction results in a high torsional impulse. Other instances of damaging torque load to vehicles or machinery may occur when there is necessity to accelerate or decelerate large masses. Short-term peak torques often need to be limited without interrupting work. Fatigue and overload damage due to shock, impact loading, directional changes and can cause torque overload damage and component failure.

[0046] Figure 10 illustrates torque transmitted by a typical drive train component resulting spike in torsional stress, oal. Figure 11 is a graph showing torque transmitted by a tolerance ring of the present invention. It can be seen that
the torsional impulse is truncated when the torque-slip capacity is exceeded, resulting in a peak stress, $\sigma a2$.

[0047] Figure 12 illustrates a typical SN fatigue curve. The y-axis is the peak stress amplitude (logarithmic scale), and the x-axis is the logarithmic number of load cycles (also logarithmic scale). If the ultimate strength of the material is exceeded then the material fails in one cycle. In this example if the peak stress is at the yield strength of the material then the part fails in 10,000 cycles. If the peak stress $\sigma a1$ seen in Figure 10 is reached $N1$ times the part will fail. If the peak stress $\sigma a2$ is reached $N2$ times the part will fail, but the part will have lasted $N2-N1$ cycles longer. Since the scale is logarithmic this can be many thousands or in some cases infinite life. If the truncation line in Figure 11 is at the stress level equal to the fatigue strength line in Figure 12, then the fatigue life of the part is said to be infinite for the stress that is induced in the curve. The tolerance ring assembly of the present invention allows redesign of many expensive and complex power train parts, such as bearings, gears, shaft diameters, reducing costs, increasing life, reducing rotating mass and total weight.

**Torque-Limiting Components**

[0048] The present invention includes use of a tolerance ring in various vehicle, machine and equipment applications. In all applications, the tolerance ring functions in a similar manner, namely transferring torque up to a predetermined design limit and then slipping to non-destructively limit torque. In practice, the components for each specific application will be optimized and may require additional parts such as oil or grease seals, seal grooves, snap rings, and snap ring grooves, without limitation.
Torque-Limiting Universal- CV Joint

[0049] Referring to Figures 13 and 14, a torque limiting constant velocity (CV) joint assembly 40 includes a ball-type constant velocity joint 43. A splined shaft 43a drivingly engages a splined inner race of the joint as shown. A tolerance ring 41 having equally circumferentially spaced, radially outwardly extending corrugations 46 is positioned over the smooth outer cylindrical surface 45 of the joint outer race. The smooth inner surface of the tolerance ring 41 is in frictional contact with the outer cylindrical surface 45. A housing 42 has a series of equally circumferentially spaced grooves 44 cut or broached into the inner surface bore. The grooves correspond in number, shape and spacing to the tolerance ring corrugations 46 to mechanically circumferentially lock the tolerance ring 41 to the outer race 42. The constant velocity joint 43 may be of any type, including fixed center, plunging, cross-groove, double Cardan, etc., or even a Cardan universal joint. It will be understood by those skilled in the art that the torque-limiting assembly will only minimally increase the diameter of the assembly 40.

[0050] Figures 15 and 16 show a variant type of torque-limiting CV (constant velocity) joint assembly 45 using an internally corrugated tolerance ring. Figure 15 shows an exterior view. Figure 16 shows an internally corrugated tolerance ring 41a having equally circumferentially spaced and radially inwardly extending corrugations 46a. An exterior housing 47 has a bore with a smooth internal cylindrical surface 47a and an extending splined portion 49. CV joint 43b includes axially extending and circumferentially spaced grooves 48 on its exterior surface, each groove 48 corresponding to an internal tolerance ring corrugation 46a.
Torque Limiting Wheel Hub

[0051] Figures 17 and 18 show a torque limiting wheel hub 50 with a tolerance ring 51 positioned within a wheel hub of a full-floating type live axle. Wheel hub 52 includes a flange portion 52a secured by bolts. Tolerance ring 51 includes radially outwardly extending corrugations which drivingly engage corresponding grooves 54 on the radially inside surface of the flange 52a. The radially inner surface of the tolerance ring 51 is smooth and frictionally engages a smooth radially outer cylindrical surface of a friction disc 53f. An axle shaft 13 is splined to the friction disc 53f. Figure 18 is an assembled sectional view of Figure 17.

Torque Limiting Axle Shaft

[0052] Referring to Figures 19, 20 and 21, a torque limiting half-shaft axle assembly 60 includes an inner shaft 63 having a splined end portion 65 and six equally axially spaced integral annular ridges 66. The shaft 63 has smooth cylindrical surfaces 67 between each set of two annular ridges. Five axially spaced tolerance rings 61 are positioned around the shaft 63, each tolerance ring positioned between two ridges 66. Each tolerance ring 61 has equally circumferentially radially outwardly extending corrugations 68 and a smooth radially inner surface 69. The smooth inner surface 69 of each tolerance ring is in frictional engagement with a corresponding smooth cylindrical surface 67 of the inner shaft 63.

[0053] The assembly 60 includes an outer shaft 62 having a splined end 58 and a sleeve portion 59. The radially inner surface of the sleeve portion 59 defines circumferentially spaced grooves 64 corresponding to the tolerance ring corrugations 68. When assembled, the tolerance ring corrugations 68
mechanically rotationally lock the tolerance rings 61 to the outer shaft 62, while the smooth inner surface of the tolerance rings frictionally engage the smooth outer cylindrical surfaces 67 of the inner shaft, thereby limiting the maximum torque transmitted between the inner and outer shafts. Fig. 21 shows an exterior view of assembly 60. The compact nature of the assembled design can be seen in Figure 21.

[0054] Figure 22 shows an exterior view of a torque-limiting axle shaft 70 configured to replace a Volkswagen swing-axle type shaft. Figure 23 shows an alternative torque-limiting axle shaft assembly 80 configured to replace a standard live axle shaft. The torque-limiting components can be similar to those of assembly 60. The assembly 80 includes an outer shaft flange 81 for driving connection with a vehicle wheel and splines 82 for driving connection with an axle side gear.

[0055] Figure 24 shows a torque-limiting axle shaft assembly 85 configured to replace a propeller shaft, power-take-off shaft, or any of various other power transmission shafts. The torque-limiting components can be similar to those of assembly 60. The inner and outer shafts of the assembly 85 are sealed to contain lubricating fluid. The shaft end portions 86, 87 can be configured with a yoke for an automotive type Cardan universal joint or a flange or other means for a driving connection in a power train, without limitation.

[0056] It is understood that the internal components of Figures 19 through 25 can be configured in either the externally corrugated tolerance ring format of assembly 40 Figures 14, 15, 17, 18, 19, 20, and 21 or the internally corrugated tolerance ring format of assembly 45, Figures 15 and 16.
Torque-Limiting Differential

[0057] Referring to Figures 25, 26A and B, an open differential 90 includes two tolerance rings 91, each engaging one of the two side gears 92. The structure of one side of the differential will be described, the other side being similar. Tolerance ring 91 is positioned between the internal cylindrical surface of side gear 92 and the external cylindrical surface of a friction disc 93 that is splined to axle shaft 93a. The tolerance ring 91 includes equally circumferentially spaced radially inwardly extending corrugations circumferentially locked into corresponding grooves 94 in the external cylindrical surface of the sleeve 93, as more clearly seen in Figure 26A. The smooth radially outer surface of the tolerance ring 91 frictionally engages the smooth radially inner cylindrical surface of the side gear 92. Differential housing lubricant will provide lubrication to the tolerance rings. The tolerance ring 91 will limit torque transfer between the side gear 92 and the axle shaft 93a.

[0058] Alternatively, referring to Figure 26B, tolerance ring 91’ may have radially externally extending corrugations circumferentially locked into corresponding grooves 94’ provided in the inner circumferential surface of the side gear 92’. With this configuration, the smooth radial inner surface of the tolerance ring 91’ will frictionally engage the smooth outer cylindrical surface of the friction disc 93’.

Manual Torque Limit Adjustment

[0059] Referring to Figure 27A, a manually adjustable tolerance ring torque-limiter. Tolerance ring 101 is positioned between an inner shaft 103 and an outer adjusting split ring 102a. The split ring 102a has radially extending adjacent ears 105 which are provided to change the inner diameter of the split ring. The
tolerance ring 101 may have radially inwardly or outwardly extending corrugations, with the cylindrical surfaces of the inner shaft 103 and split ring 102a having grooves and a smooth surface, or a smooth surface and grooves, respectively, as previously described.

[0060] Referring to Figure 27B, a housing 102b surrounds and houses the split ring 102a. The housing 102b includes a slot 106 for accepting the split ring ears 105. When the assembly shown in Fig. 27A is placed into housing 102b, there can be a range of compression values on the tolerance ring 101. Threaded bores 107 extend through the outer surface of the housing 102b to the walls of the slot 106. One or two set screws 112 may be threaded into the threaded bores into contact with one or both of the ears 105 to decrease or increase the diameter of the split ring. The use of opposing set screws 112 is preferred for balance and for providing maximum compressive force. Clamping forces applied to the split ring ears 105 will change the diameter of the split ring 102a and change the compression of the tolerance ring corrugations between the inner shaft 103 and split ring 102b, thereby changing the torque limit of the device.

[0061] Referring to Figure 27C, set screws 112 of the embodiment of Figure 27A have been replaced by an Allen head pinch bolt 113 in a bore 114 of the modified split ring 102c. Figure 27D shows the assembled device with the Allen-head pinch bolt 113 in a bore 115 of the housing 102d. It is understood that other means may be used in compressing the split-ring ears 105, without limitation.

[0062] In both embodiments of Figures 27A and 27C, the gap in the tolerance ring accommodates any diameter change in the tolerance ring. This
simple mechanical adjustment of the torque slip values allows for fine tuning to compensate for manufacturing tolerances, wear, and torque-transfer value. This is particularly useful for vehicle racing applications.

**Automated Torque Limit Adjustment**

[0063] Referring to Figure 28, a tolerance ring 121 is positioned between an inner shaft 123 and an outer member 122. The tolerance ring has radially outwardly extending corrugations which circumferentially lock the tolerance ring to the outer member 122 through grooves 124, as previously described. Alternatively, a tolerance ring with radially inwardly extending corrugations may be circumferentially locked to grooves in the outer surface of the inner shaft 123. The outer member 122 includes an axially extending flange 126 with a frusto-conical outer surface and four or more diametrically opposed slots 127 to allow diameter changes of the flange. An annular pressure collar 123p engages the outer surface of the frusto-conical flange 126. A computer actuated annular pressure bearing 125, similar to a clutch-release bearing used in an automotive bell housing, is axially driven by a hydraulic pump, similar to the Audi Quattro system, to instantaneously adjust the diameter of the flange. The clamping force of the flange 126 on the tolerance ring 121, varied by the axial movement of the pressure collar 123p, increases or reduces the inner diameter of the flange, thereby changing compression and torque-transfer value of the tolerance ring 121. Release spring pack 128 may be used to bias the pressure ring 123p and pressure bearing 125 in a direction opposing the hydraulic pump bias direction. Referring to Figure 29 showing an external view of Figure 28 assembled.

[0064] The devices shown in Figures 28 and 29 are energy-applied types of clutches. There are two basic types of clutch; energy applied (spring release)
and spring applied (energy release). An energy-applied clutch is said to be "normally disengaged" because no torque is transmitted to the driven device until actuation energy is applied (as in Figures 28 and 29). A spring-applied clutch is referred to as "normally engaged", meaning that, in the absence of actuating power, the clutch will transmit torque, and actuation energy is required to disengage it. To change the functions of the devices in Figures 28 and 29 to a "normally engaged" or (energy release) clutch, the positions of the spring packs 128 and the annular pressure bearings 125 are reversed and the direction of actuation of the pressure bearings 125 is also reversed. Spring force will cause the pressure collar 123p to compress the flanges 126 and the tolerance rings 121 and thus the clutch will be constantly engaged. When energy is applied to the annular pressure bearings 125, the pressure collars 123p will release compression on the flanges 126 and tolerance rings 121 and the clutches will cease to transmit torque. The described devices can provide a range of actuation and release speeds and control acceleration and deceleration and can be actuated by mechanical, electric, hydraulic and pneumatic (air) means.

**Drive Train Applications**

[0065] Referring to Figure 30, various power or drive train configurations include a power source 200 that drives a driven device 300 through a torque-limiting assembly 100. The assembly 100 may be any of the constant torque, manually adjustable, or automatically adjustable torque-limiting devices described herein. The tolerance ring assembly 100 may be positioned in a drive shaft or axle, a sheave, a pulley, a gear or gear train, etc. The drive train may be used in numerous types of machines or vehicles, including automotive, heavy truck and racing vehicles, farm vehicles such as mowers, bailers, combines, sorters, pickers, tractors, harvesters, construction vehicles, motorcycles, ATVs, off-road, specialty
and maintenance vehicles, inboard and outboard marine vehicles, jet and propeller driven aircraft and hover-craft, railroad vehicles, etc.

[0066] The drive train also may be used in numerous types of machinery and equipment, including oil drilling and processing equipment, mining, construction, electric generation, farm, packaging, metal smelting, and metal forming equipment, wind power generation, lumber, logging, wood processing, printing, brewing, chemical, paper and steel manufacturing equipment; mills and milling machinery, CNC machines, lathes, conveyer belts, washing machines, computers and hard drives, rotary cutters, linear and other actuators, pulleys and sheaves, clutches, including over-running clutches, turbines, robots, torque converters, hand and power tools, machine tools, compressors, fans, turbine wheels, power take-off units, sprockets, bushings, speed reducers, collars, adaptors, etc.

[0067] Referring to Figure 31, a torque-limiting drive train in a two-wheel drive, front wheel drive land vehicle includes a power source 200, driven devices including a transmission 310, a differential 320, driven road wheels or tracks 330, and torque-limiting assemblies 100 positioned at various locations in the drive train, and un-driven road wheels 330a. Referring to Figure 32, a torque-limiting drive train in a two-wheel drive, rear wheel drive land vehicle includes a power source 200, driven devices including a transmission 310, a differential 320, driven road wheels or tracks 330, and torque-limiting assemblies 100 positioned at various locations in the drive train, and un-driven road wheels 330a. In Figure 33, an all-wheel drive or 4-wheel drive vehicle includes a power source 200 and driven devices including a transmission 310, transfer case or center differential 315, front and rear differentials 320, driven road wheels or tracks 330, and torque-limiting assemblies 100 positioned at various locations in the drive train. It is
understood that many other configurations of drive trains, driven and un-driven road wheel, tracks other means of propulsion and are possible. The assemblies 100 may be any of the constant torque, manually adjustable, or automatically adjustable torque-limiting devices described herein. While numerous torque-limiting devices 100 are shown in Figures 31, 32 and 33. It will be understood by those skilled in the art that a single torque-limiting assembly 100, or any number of assemblies 100 may be adequate or optimum for a particular vehicle.

Summary of Operation

[0068] All of the previously described assemblies have predetermined torque limits. When the predetermined torque limit is exceeded, either the external and internal components will rotate relative to the other, i.e. slip. The desired component will remain locked to the tolerance ring while the other component will slip, depending on whether the tolerance ring has radially inwardly or outwardly extending corrugations.

[0069] There are many ways to mechanically circumferentially lock rotation of a tolerance ring relative to a drive or driven component. The embodiments described above utilize tolerance ring corrugations engaging mating grooves in a drive or driven component to lock relative rotation. The axially extending grooves may be of a predetermined depth and design, and can be formed by cutting into the interior bore of a housing or the exterior surface of a shaft by broaching, CNC, or EDM. Grooves can also be formed by net form casting, additive manufacturing or other processes known to the art, without limitation.
Advantages

[0070] By limiting torque, drive train components can safely be designed with reduced load capacity. The present invention allows redesign of many expensive and complex power train parts such as bearings, gears, gear teeth, and shaft sizes, while increasing component life and saving energy by reducing rotating mass and total weight. Drive trains designed in accordance with the present invention can meet all conditions required to safely transmit required torque and prevent mechanical failure in automotive, industrial and machine applications, thereby providing additional levels of human safety and preventing damage to machinery and equipment power trains. The present invention can provide durable, light, simple, inexpensive, and compact power trains for a wide range of static or adjustable torque transfer and limitation values, transmit desired torque reliably with repeated overloads with a long service life. The present invention allows a wide range of placement options in a drive train and can be easily and inexpensively rebuilt to compensate for wear or change of torque value. The present invention also allows an aftermarket manufacturer to offer a wide range of inexpensive, durable and effective torque limiting components in many types of vehicles.

[0071] The present invention allows the use of tolerance rings as frictional clutches with wider ranges of stable torque-transfer and greatly increased durability. It is preferable for the smooth or non-corrugated side of the tolerance ring to provide the frictional engagement with one component while the corrugated side remains locked to the other component. One or more axial grooves, corresponding to the shape and pitch of the tolerance ring corrugations, provides a very durable means of long term torque transfer. Each groove takes part of the frictional load so the total load on the corrugated side of the ring is evenly divided by the number of corrugations on the ring.
[0072] Alternative methods of mechanically locking a tolerance ring to a drive or driven component may also be utilized, such as keys, dowels, pins, etc. However, corrugations locked into grooves as described herein allows more secure locking compared to a single key, pin, set screw or other device.

[0073] The principles of the present invention apply to any type of material or configuration of externally or internally corrugated tolerance ring and the related components, rotating in either direction. The descriptions of specific embodiments of the invention herein are intended to be illustrative and not restrictive. The invention may be practiced otherwise than as specifically explained and illustrated without departing from its spirit or scope as defined by the appended claims.
WHAT IS CLAIMED IS:

1. A drive train comprising a drive component, a driven component and a tolerance ring drivingly connecting the drive and driven components, the tolerance ring having an axis of rotation,
   wherein the tolerance ring is rotationally fixed to one of the drive component and driven component and frictionally engaged with the other of the drive component and driven component, and
   wherein one of the drive component and driven component is a pulley, a sheave, a gear, a bushing, a coupling, a universal joint, an axle shaft, a driveshaft, a bearing, a track, or a wheel.

2. A drive train component as defined in claim 1 wherein the drive train is in a vehicle, a hand tool, a power tool, or a machine.

3. A drive train as defined in claim 2 wherein the drive train is in a land vehicle.

4. A drive train as defined in claim 2 wherein the drive train is in a marine vehicle.

5. A drive train as defined in claim 2 wherein the drive train is in an aircraft vehicle.

6. A drive train as defined in claim 3 wherein the drive train is in a farm vehicle.

7. A drive train as defined in claim 3 wherein the drive train is in a mining vehicle.
8. A drive train as defined in claim 2 wherein the drive train is in an industrial machine.

9. A drive train as defined in claim 2 wherein the drive train is in an electronic device.

10. A drive train as defined in claim 9 wherein the electronic device is a computer hard drive.

11. A drive train as defined in claim 1 wherein the tolerance ring has a radially inner surface and a radially outer surface, and wherein the tolerance ring is rotationally fixed to one of the drive component and driven component by corrugations on one of the inner surface and outer surface and grooves on the other of the inner surface and outer surface, each corrugation positioned in a groove.

12. A drive train as defined in claim 1 comprising a screw rotationally affixing the tolerance ring to one of the drive component and driven component.

13. A drive train as defined in claim 1 comprising a key, dowel or pin rotationally affixing the tolerance ring to one of the drive component and driven component.

14. A drive train as defined in claim 1 wherein the other of the drive component and driven component has a generally smooth annular surface frictionally engaged with the tolerance ring.
15. A drive train as defined in claim 1 wherein there is frictional force between the tolerance ring and the other of the drive component and driven component.

16. A drive train as defined in claim 1 wherein further comprising a unidirectional rotational mechanism rotationally fixed to one of the drive component and driven component.

17. A drive train comprising:
   a drive component having an axis of rotation and a radially outer cylindrical wall,
   a driven component having a radially inner cylindrical wall coaxial with the drive component radially outer cylindrical wall,
   a tolerance ring drivingly connecting the drive component and the driven component, the tolerance ring having a radially inner and outer walls coaxial with drive component radially outer wall and the driven component radially inner wall,
   wherein the drive component outer wall comprises circumferentially spaced and generally axially extending grooves, and
   wherein the driven component inner wall comprises a plurality of radially outwardly extending domes, each dome positioned within a generally axially extending groove, and
   wherein the drive train component is a pulley, a sheave, a gear, a bushing, a coupling, a universal joint, an axle shaft, a driveshaft, a bearing or a wheel.
18. A drive train comprising:

   a driven component having an axis of rotation and a radially outer cylindrical wall,

   a drive component having a radially inner cylindrical wall coaxial with the driven component radially outer cylindrical wall,

   a tolerance ring drivingly connecting the drive component and the driven component, the tolerance ring having a radially inner and outer walls coaxial with driven component radially outer wall and the drive component radially inner wall,

   wherein the driven component outer wall comprises circumferentially spaced and generally axially extending grooves, and

   wherein the drive component inner wall comprises a plurality of radially outwardly extending domes, each dome positioned within a generally axially extending groove, and

   wherein the drive train component is a pulley, a sheave, a gear, a bushing, a coupling, a universal joint, an axle shaft, a driveshaft, a bearing or a wheel.
INTERNATIONAL SEARCH REPORT

INTERNATIONAL APPLICATION No. PCT/US2015/063911

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F16D 7/02 (2016.01)
CPC - F16D 7/02 (2016.01)

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) F16D 700, 702, 704 (2016.01)
CPC - F16D 700, 702, 7021 (2016.01)

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

USPC - 403/367 (Keyword delimited)

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

Orbit, Google Patents, Google Scholar, Google

Search terms used: tolerance, ring, torque, limit, drive, shaft, rotational, frictional, lock, screw, corrugation, groove, spline, coupling

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>US 20050252327 A1 (SHOGREN et al) 17 November 2005 (17.1 1.2005) entire document</td>
<td>1-1 1, 14, 15, 17, 18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12, 13, 16</td>
</tr>
</tbody>
</table>

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

* Special category of cited documents:

A - document defining the general state of the art which is not considered to be of particular relevance

E - earlier application or patent but published on or after the international filing date

L - document which may throw doubts on priority claim(s) or which is cited to establish thepublication date of another citation or other special reason (as specified)

O - document referring to an oral disclosure, use, exhibition or other means

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

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

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

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

* - document member of the same patent family

Date of the actual completion of the international search: 26 January 2016

Date of mailing of the international search report: 05 FEB 2016

Name and mailing address of the ISA/Authorized officer

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents

Blaine R. Copenhaver

P.O. Box 1450, Alexandria, VA 22313-1450

PCT Helpdesk: 571-272-4300

PCT OSP: 571-272-7774

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