

Co-Rotational Scroll Apparatus

The invention relates to co-rotational scroll apparatus having coupling means for causing concurrent rotation of the scroll members and the use of the coupling means to enhance the nutational stability of the scroll apparatus.

Scroll apparatus for fluid compression or expansion are typically comprised of two upstanding interfitting involute spiroidal wraps which are generated about respective axes. Each respective involute wrap is mounted upon an end plate and has a tip disposed in contact or near-contact with the end plate of the other respective scroll wrap. Each scroll wrap further has flank surfaces which adjoin in moving line contact, or near contact, the flank surfaces of the other respective scroll wrap to form a plurality of moving chambers. Depending upon the relative orbital motion of the scroll wraps, the chambers move from the radially exterior end of the scroll wraps to the

radially interior ends of the scroll wraps for fluid compression, or from the radially interior end of the respective scroll wraps for fluid expansion. The scroll wraps, to accomplish the formation of the chambers, are put in relative orbital motion by a drive mechanism which constrains the scrolls to relative non-rotational motion. The general principles of scroll wrap generation and operation are discussed in numerous patents, such as U.S. Patent Number 801,182.

Numerous attempts have been made to develop co-rotational scroll apparatus. Such apparatus provides for concurrent rotary motion of both scroll wraps on parallel, offset axes to generate the requisite orbital motion between the respective scroll wrap elements. However, most commercially successful scroll apparatus to date have been of the fixed scroll-orbiting scroll type due to various difficulties in achieving success with co-rotating scroll apparatus.

Typically, a number of rotary bearings are required in a co-rotational scroll apparatus, which decreases the reliability and efficiency of the machine. Furthermore, the typical co-rotating scroll apparatus have required a thrust bearing acting upon each of the scroll end plates to prevent axial scroll separation, thus substantially increasing the power requirements of the machine as well as substantially reducing the reliability of the machine.

An additional problem which must be dealt with in scroll apparatus, whether used for compression or decompression of fluid, are the forces which result from the fluid trapped in the chambers formed in the scroll wraps. These forces include an axial separation force component resulting from the fluid

pressure upon the scroll element end plates and a radial separation force resulting from the fluid pressure upon the scroll wraps themselves. Furthermore, the separation forces due to the fluids compressed within the scroll elements vary cyclicly as the scroll elements rotate. This cyclic variation is a function of two factors. The first is the instantaneous location of each of the compression chambers formed by the scroll wraps during each revolution. The chamber location is a function of the angular and radial disposition of the center of the chamber with respect to the center of the scroll apparatus at a given crankangle. The second is the actual pressure of the compressed fluid, which varies according to the instantaneous location of the compression chamber in which the fluid is contained, decreasing from the radially inner ends of the respective scroll wraps to the radially outer ends thereof. Both these factors combine to produce a moment, the product of the instantaneous center of the compression chamber location and the instantaneous fluid pressure forces at that location. The resulting tipping moment upon the scroll member is the net effect of the moments developed by each compression chamber. The tipping moment acts perpendicularly to the axis of rotation of the scroll member, and therefore seeks to cause the tipping of the scroll element. Since the magnitude of the tipping moment is more pronounced at various crankangle positions during the rotation of the scroll element, actual tipping may occur at some crankangle positions, while it may be prevented at other positions by other forces sufficiently exerted on the scroll members. Actual tipping is observable as a rocking or nutation of the scroll member during rotation.

Typically, this is dealt with by the provision of an axial force acting to compress the end plates of the scroll elements together, in opposition to the separating fluid forces and by the provision of relatively larger bearings. These
5 compressive axial forces are typically induced either mechanically by such means as thrust bearings or springs, or by fluid pressure imposed upon the opposite side of the scroll end plate.

Prior scroll apparatus attempt to counter the
10 nutation effect by simply increasing the axial force loading upon the scroll end plate until the tipping moments are overcome, by providing a large number of bearings for supporting the scroll member shafts to prevent the shaft misalignment which occurs during tipping, and by decreasing the
15 manufacturing tolerances of the components. All of these solutions increase the size and number of components of the scroll apparatus as well as the initial and operating costs, and also decrease the expected operating life of the scroll apparatus.

20 These solutions also undesirably affect the performance of the scroll apparatus as well. Because the axial force provided remains constant at any given operating condition, the axial force loading remains relatively high even when the separation effects of the tipping moment are low,
25 which is typically the case during most of the scroll rotary cycle. Hence, there are unnecessarily high forces acting upon the scroll wrap tips at many crankangle positions in the scroll cycle, with resulting unnecessary friction and wear as well as excessive power consumption and loss of overall efficiency.

Furthermore, even when the axial force loading is relatively high, tipping of the scroll member can occur at some crankangle positions during rotation of the scroll apparatus. When nutation of the scroll element does occur, the scroll wrap tips can momentarily separate from the opposing scroll end plate. This permits fluid to pass from higher pressure compression chambers to lower pressure chambers, requiring recompression of the fluid and again reducing the overall efficiency of the scroll apparatus.

In co-rotational scroll apparatus having a coupling engaging the scroll members for causing the concurrent scroll rotation, an additional moment is caused by the action of the coupling in the apparatus. This is due to the rotation of the mass of the coupling, which rotates about a point defined between the axes of the scroll members. Since the center of rotation of the coupling is not concurrent with the center of the scroll members, nutation of the scroll members may be induced by the coupling due to the moment generated by the offset of the coupling mass with respect to the axis of the scroll members. The nutation causing effect of the coupling may be even more pronounced in cases where the center of gravity of the coupling mass is not identical with the physical center of the coupling, so that the offset of the coupling mass is increased.

The typical solutions applied to the tipping effects of the coupling are identical to those applied to the scroll members themselves and the identical consequences may be observed.

It is an object of the invention to provide such a scroll apparatus as will reduce and moderate the scroll member net tipping moment in a rotating scroll apparatus by appropriate disposition of a drive coupling.

Accordingly, the invention provides a co-rotational scroll apparatus having coupling means coupling first and second scroll members thereof for concurrent rotation about parallel spaced axes, the mass of the coupling being disposed such that it produces a moment opposing the respective tipping moment about the respective said axis of at least one of the scroll members at a crankangle where said tipping moment is a maximum.

The invention includes a co-rotational scroll apparatus comprising:

a first scroll member comprising a first scroll end plate, a first scroll wrap including a first upstanding involute portion disposed on said first scroll end plate, and a drive shaft disposed on said first scroll end plate, said first scroll member having an axis of rotation and being subject, in use of the apparatus, to a tipping moment about said axis of rotation which tipping moment varies according to the angle of rotation of said first scroll member;

a second scroll member comprising a second scroll end plate, a second scroll wrap including a second upstanding involute portion disposed on said second scroll end plate, said second scroll member having an axis of rotation and being subject, in use of the apparatus, to a tipping moment about said axis of rotation which tipping moment varies according to the angle of rotation of said second scroll member;

a coupling means for coupling said first scroll member and said second scroll member, said coupling means being positioned so as to provide, in use of the apparatus, a predetermined moderating moment for enhancing the nutational stability of said scroll apparatus by reducing the magnitude of the maximum said tipping moment to which at least one of said

scroll members is subjected; and

means for rotating said first scroll member.

The invention further includes a co-rotational scroll apparatus comprising:

5 a hermetic shell having a suction pressure portion for containing a suction pressure fluid;

a first scroll member disposed in said suction pressure portion, said first scroll member having a first scroll end plate, a first scroll wrap including
10 a first upstanding involute portion disposed on said first scroll end plate, and a drive shaft disposed on said first scroll end plate, said first scroll member being subject in use of the apparatus to a tipping moment about the axis of said drive shaft which
15 tipping moment varies as the first scroll member rotates;

a second scroll member disposed in said suction pressure portion, said second scroll member having a second scroll end plate, a second scroll wrap
20 including a second upstanding involute portion disposed on said second scroll end plate, and an idler shaft disposed on said second scroll end plate, said second scroll member being subject in use of the apparatus to a tipping moment about the axis of said
25 idler shaft which tipping moment varies as the second scroll member rotates;

coupling means for drivingly coupling said first scroll member and said second scroll member, said coupling means being positioned such that at an
30 angular position of said scroll members at which said first and second scroll wraps make initial contact to define a closed radially outermost chamber therebetween, a center of gravity of the coupling means has a predetermined angular position relative to
35 a point on a reference line passing through the

respective axis of said drive and idler shafts to produce, in use of the apparatus, a moderating moment which enhances the nutational stability of said scroll apparatus by acting in opposition to and thereby reducing the tipping moment of at least one of said scroll members;

means for rotatably supporting said idler shaft in said suction portion of said hermetic shell; and

means for rotating said drive shaft.

The invention further includes a refrigeration system for circulating refrigerant in closed loop connection, said system comprising:

a condenser for condensing refrigerant to liquid form;

an expansion device for receiving liquid refrigerant from said condenser and expanding the refrigerant;

an evaporator for receiving the refrigerant from said expansion device and evaporating the refrigerant to vapor form; and

a compressor for receiving the refrigerant from the evaporator, compressing the refrigerant, and sending the refrigerant to the condenser, said compressor comprising:

a hermetic shell having a suction pressure portion for containing a suction pressure fluid;

a first scroll member disposed in said suction pressure portion, said first scroll member having a first scroll end plate, a first scroll wrap including a first upstanding involute portion disposed on said first scroll end plate, and a drive shaft having an axis of rotation and being disposed on said first scroll end plate, said first scroll member being subject in use of the apparatus to a tipping moment about said axis of rotation which tipping moment

varies as the first scroll member rotates;

5 a second scroll member disposed in said suction pressure portion, said second scroll member having a second scroll end plate, a second scroll wrap including a second upstanding involute portion disposed on said second scroll end plate, and an idler shaft having an axis of rotation and being disposed on said second scroll end plate, said second scroll member being subject in use of the apparatus to a
10 tipping moment about said axis of rotation of the idler shaft which tipping moment varies as the second scroll member rotates;

coupling means for drivingly coupling said first scroll member and said second scroll member, said
15 coupling means being disposed such that at an angular position of said scroll members at which said first and second scroll wraps make initial contact to define a closed radially outermost chamber therebetween, a center of gravity of the coupling means has a
20 predetermined angular position relative to a point on a reference line passing through the respective axis of said drive and idler shafts to produce a moderating moment which enhances the nutational stability of said scroll apparatus by acting in opposition to and
25 thereby reducing the magnitude of the maximum said tipping moment acting on a selected one of said scroll members;

means for rotatably supporting said idler shaft in said suction portion of said hermetic shell; and
30 means for rotating said first scroll drive shaft.

The invention further includes a method of enhancing the nutational stability of a co-rotational scroll apparatus having a first scroll member and a second scroll member which are in interleaving
35 engagement, said scroll members each being subject, in

use of the apparatus, to a tipping moment about the respective axis of rotation thereof the method comprising the steps of:

5 determining for at least one of said scroll members the maximum said tipping moment to which that scroll member is subject and a rotational position of that scroll member at which said maximum tipping moment occurs; and

10 engaging said first scroll member and said second scroll member with a coupling, said coupling being disposed such that during said use, the moment produced by said coupling due to the location of its centre of gravity reduces said maximum tipping moment.

15 The invention further includes a method of enhancing the nutational stability of a co-rotational scroll apparatus having a driven scroll member and an idler scroll member, said driven scroll member having an axis about which it rotates through a cycle of angular positions and including a first involute scroll wrap, said idler scroll member having an axis about which it rotates through said cycle of angular positions and including a second involute scroll wrap in interleaving engagement with said first scroll wrap, and said driven scroll member and said idler scroll member being subject during operation of the apparatus to a respective tipping moment about the respective said axis of rotation thereof, said method comprising the steps of:

20 determining a reference position of said scroll members at which said first and second scroll wraps form a first chamber;

25 determining at least for the idler scroll member, the instantaneous tipping moment to which said scroll member is subject at each said angular position;

30 determining at least for the idler scroll member

the maximum of said instantaneous tipping moments and the angular position of the scroll member relative to said reference position when said maximum tipping moment occurs;

5 determining for said reference position an angular position relative to a point on a reference line passing through the respective axis of rotation of said driven and idler scroll members at which to position a mass for producing a moderating moment for counteracting at least said maximum tipping moment to
10 which said idler scroll member is subject; and

 engaging said driven scroll member and said idler scroll member with a coupling means having a predetermined mass such that at said reference
15 position of the scroll members, a center of gravity of the coupling means is disposed at said angular position relative to a point on said reference line for producing said moderating moment during operation of the apparatus.

20 Preferred embodiments of the invention described hereinafter disclose a method and means for enhancing the rotational stability of at least one of the scroll members, or elements, of a co-rotational scroll apparatus having two concurrently rotating scroll
25 members, each scroll member including an end plate and a scroll wrap thereon having at least an involute portion for interleaving engagement with the scroll wrap of the other scroll member and rotating on an axis parallel to the axis of the other scroll member.

30 It will be understood that a coupling engaging one or both of the scroll members in a co-rotational scroll apparatus can be an Oldham-type drive coupling for ensuring concurrent rotation of the scroll members and that while the shape of the coupling can readily
35 be varied, the coupling has a mass which locates or

defines a coupling center of gravity. The coupling is positioned such that this center of gravity is disposed so that the mass of the coupling produces a moment opposing the tipping moment generated within the scroll members in the range of crankangle positions where tipping is most likely to occur. The coupling moment so generated may be referred to as a moderating moment. The coupling may also include an additional mass disposed on the coupling to further alter the disposition of the coupling center of gravity. By generating a moment in opposition to the tipping moment of the scroll members, the nutational stability of the scroll members during rotation is enhanced.

In order to enhance the nutational stability of a co-rotational scroll apparatus, the magnitude of the instantaneous moment, the so-called tipping moment, resulting from fluid forces acting upon a scroll member about the axis of rotation of the scroll member is determined for each radial point or angular position throughout the rotation of the scroll member. From this, the maximum tipping moment acting upon the scroll member and the range of angular, or crankangle, positions of the scroll member at which the maximum tipping moment acts can be found. The instantaneous moment generated by the coupling, also referred to as the moderating moment, can also be determined as a function of the mass of the coupling and the relative position of the center of gravity of the coupling. The angular disposition of the coupling necessary to provide a moderating moment to moderate or reduce the maximum determined tipping moment of the scroll members to a desired extent is then also determined. The coupling is then placed at the predetermined angular position to reduce the nutation of the scroll

members.

In order that the invention may be well understood, the above-mentioned embodiments thereof which are given by way of example only, will now be described in more detail with reference to the accompanying drawings, in which:

Figure 1 is a cross-sectional view of a co-rotational scroll apparatus;

Figure 2 is a schematic representation of a refrigeration system in which a co-rotational scroll apparatus can be suitably employed;

Figure 3 is a cross-sectional view of the scroll apparatus of Figure 1 (without an additional mass 140) taken along section lines 3-3;

Figure 3A is a partial enlargement of the view of Figure 3;

Figure 4 shows the effect of tipping moments upon a representative co-rotational scroll apparatus;

Figure 5 is a diagram representative of the combined tipping moment and moderating moment, and of the axial scroll tip contact force acting upon one of the scroll members during the rotation of the scroll member in a co-rotational scroll apparatus;

Figure 6 is a diagram representative of the tipping moment as combined with various moderating moments, acting upon one of the scroll members during the rotation of the scroll apparatus; and

Figure 7 shows the scroll apparatus of Figure 3 with the additional mass 140.

A co-rotational scroll type fluid apparatus generally shown in Figure 1 as a scroll compressor assembly is referred to by reference numeral 20. As the preferred embodiment is a hermetic scroll compressor assembly, the co-rotational

scroll apparatus 20 is interchangeably referred to as a scroll compressor 20 or as a compressor assembly 20. It will be readily apparent that the features of the compressor assembly will lend themselves equally readily to use in a scroll apparatus acting as a fluid expander, a fluid pump, or to scroll apparatus which are not of the hermetic type.

In the preferred embodiment, the compressor assembly 20 includes a hermetic shell 22 having an upper portion 24, a lower portion 26, a central exterior shell 27 extending between the upper portion 24 and lower portion 26, and an intermediate, central frame portion 28 affixed within the central exterior shell 27. The exterior shell 27 is a generally cylindrical body, while the central frame portion 28 is defined by a generally cylindrical or annular exterior portion 30 and a central portion 32 disposed across one end thereof. The annular exterior portion 30 of the central frame portion 28 is sized to sealingly fit within the exterior shell 27 so that it may be mated thereto by a press fit, by welding, or by other suitable means.

Integral with the central frame portion 28 is a generally cylindrical upper bearing housing 34, which is substantially coaxial with the axis of the annular exterior portion 30. A drive shaft aperture 36 extends axially through the center of the upper bearing housing 34, and an upper main bearing 38 is disposed within the drive shaft aperture 36. Preferably, the upper main bearing 38 is made, for example, of sintered bronze or similar material, but may also alternatively be a roller or ball-type bearing, for accepting a rotating load therein.

A motor 40 is disposed within the upper portion 24 and central shell portion 27 of the hermetic shell 22. The motor 40 is preferably a single-phase or three-phase electric motor comprised of a stator 42 which is circumferentially disposed about a rotor 44, with an annular space formed therebetween for permitting free rotation of the rotor 44 within the stator 42 as well as the flow of lubricant or refrigerant fluid.

It will be readily apparent to those skilled in the art that alternative types of motors 40 and means of mounting motor 40 would be equally suitable for application in the compressor assembly 20. For example, the stator 42 could be secured within the central shell portion 27 by a press fit therebetween. Alternatively, a plurality of long bolts or cap screws (not shown) may be provided through appropriate apertures in the stator plates into threaded apertures in the central frame portion 28 for securing the motor 40 within the hermetic shell 22.

The scroll arrangement includes a first or drive scroll member 76 and a second or idler scroll member 78, each having an upstanding involute scroll wrap for interfitting engagement with the other respective scroll wraps. The first scroll member 76 includes an upstanding first involute scroll wrap 80 which is integral with a generally planar drive scroll end plate 82. The drive scroll end plate 82 includes a central drive shaft 84 extending oppositely the upstanding involute scroll wrap 80. A discharge gallery 86 is defined by a bore extending centrally through the axis of the drive shaft 84.

The discharge gallery 86 is in flow communication with a discharge aperture 88 defined by a generally central bore through the drive scroll end plate 82. The drive shaft 84 further includes a first, relatively large diameter portion 90 extending axially through the upper main bearing 38 for a free rotational fit therein, and a second relatively smaller diameter portion 92 which extends axially through the rotor 44 and is affixed thereto. The rotor 44 may be affixed to the rotor portion 92 of the drive shaft 84 by such means as a press fit therebetween or a power transmitting key in juxtaposed keyways.

The second or idler scroll member 78 includes a second, idler scroll wrap 100 which is disposed in interfitting contact with the driven scroll wrap 80. The idler scroll wrap 100 is an upstanding involute extending from an idler end plate 102. Two rectilinear idler key stubs 103 extend upwardly on the idler end plate 102, as shown in Figure 3. The idler key stubs 103 are disposed at radially opposed positions outside the idler scroll wrap 100. An idler stub shaft 104 extends from the idler end plate 102 oppositely the idler scroll wrap 100.

The designation of the drive scroll member 76 as the first scroll member and the idler scroll member 78 as the second scroll member must be understood as arbitrary, made for the purposes of ease of description and therefore not as a limitation. It would be equally accurate to designate the idler scroll member 78 as the first scroll member and the drive scroll member 76 as the second scroll member.

An annular bearing 110, which may be a sleeve bearing made of sintered bronze material, or may be of the roller or ball-type, is disposed within an annular wall defining an idler bearing housing 112 which is integral with the lower hermetic shell portion 26 as a support means for rotationally supporting the second or idler scroll member 78.

In the preferred embodiment, the drive scroll end plate 82 includes two radially opposed extension members 120 extending parallel the scroll wrap 80. The extension members 120 extend from positions near the outer periphery of the drive scroll end plate 82 and include end portions 122. The extension members 120 are also disposed at positions which are generally 90 degrees removed radially from the positions of the idler key stubs 103 when the scrolls 80 and 100 are in interleaving engagement.

Preferably, the extension members are disposed on a line EE which includes the center line, or the axis of rotation, of the scroll member 76, and hence are disposed at or substantially at 180 degrees of angular removal from each other. Likewise, the idler keys 103 are disposed on a line KK which includes the center line, or the axis of rotation, of the scroll member 78, and hence are also disposed at or substantially at 180 degrees of radial removal from each other.

A coupling in the form of a ring 130 rests on the idler scroll member end plate 102 in sliding engagement. The ring 130 is annular in form, extending noncontactingly about the radial exterior of the scroll wraps 80 and 100 and further having four rectilinear drive key slots 132a, 132b, 132c, and 132d defined through the coupling ring 130 at radially equidistant intervals of approximately 90 degrees about the

annular body of the ring 130 to comprise two pairs of oppositely disposed slots 132, with slots 132a and 132c being one pair and slots 132b and 132d being the second pair. As shown particularly in Figure 3, the ring 130 includes four generally rectilinear broadened portions through which the slots 132 are defined so that the slots 132 may be of suitable size to accommodate drive keys in sliding engagement.

The actual form of the ring 130 will depend somewhat upon the desired moderating moment sought from the coupling ring 130. The ring is preferably made of steel, aluminum or a similar material capable of suitably transmitting rotational torque between the scroll members 76 and 78. It will be appreciated that the ring 130 may be formed to contain more or less mass in different portions of the annulus of the ring 130, and that one or more additional discrete masses m_a 140 may be applied by mechanical or other means to the ring 130 for obtaining a suitably moderating moment as set forth below. For example, it is possible to form the ring 130 with a constant radial thickness so that it is generally symmetrical and the center of mass m_c of the coupling ring 130 (the center of gravity cg) is centrally disposed in the coupling 130, or to provide a ring 130 having a varying radial thickness or varying height (measured in the axial direction) so that the mass is unequally distributed about the coupling 130, with the result that the center of mass m_c of the coupling ring 130 (the center of gravity cg) is eccentrically disposed. It will be appreciated that the ring center of gravity is a displaceable center of gravity of a coupling means formed by the extension members 120, the idler keys 103 and the ring 130.

Those skilled in the art will also recognise that

there are many alternative embodiments of the coupling means formed by the extension members 120, the idler keys 103 and the ring 130. For example, the coupling means may include any

combination of key and slot arrangements, such as providing ring 130 with the extension members 120 and keys 103 affixed thereon and engaging slots formed in the respective scroll end plates. It will also be apparent that there are functionally equivalent coupling means ensuring concurrent rotation of the scroll members which may be employed which include a displaceable center of gravity for producing a moderating moment in the scroll apparatus 20.

In Figure 2, the scroll compressor assembly 20 is shown connected at the discharge aperture 50 and the suction aperture 52 to a fluid system such as generally is used in refrigeration or air conditioning systems. Those skilled in the art will appreciate that this is but one fluid system in which the scroll compressor assembly 20 could suitably be utilized, and that application of the scroll compressor assembly 20 in refrigeration and air conditioning systems is to be taken as exemplary rather than as limiting.

The refrigeration system, shown generally in schematic representation in Figure 2 in connection with the scroll compressor assembly 20, includes a discharge line 54 connected between the shell discharge aperture 50 and a condenser 60 for expelling heat from the refrigeration system and in the process typically condensing the refrigerant from vapor form to liquid form. A line 62 connects the condenser 60 to an expansion device 64. The expansion device 64 may be a thermally actuated or electrically actuated valve operated by a suitable controller (not shown), a capillary tube assembly, or other suitable means of expanding the refrigerant in the system. Another line 66 connects the expansion device 64 to an

evaporator 68 for transferring expanded refrigerant from the expansion device 64 to the evaporator 68 for the acceptance of heat and typically the evaporation of the liquid refrigerant to a vapor form. Finally, a refrigeration system suction line 70 transfers the evaporated refrigerant from the evaporator 68 to the compressor assembly 20, wherein the refrigerant is compressed and returned to the refrigeration system.

It is believed that the general principles of refrigeration systems capable of using suitably a scroll compressor apparatus 20 are well understood in the art, and that further detailed explanations of the devices and mechanisms suitable for constructing such a refrigeration system need not be discussed in detail herein. It is believed that it will also be apparent to those skilled in the art that such refrigeration or air conditioning systems may include multiple units of the compressor assembly 20 in parallel or series type connection, as well as multiple condensers 60, evaporators 68, or other components and enhancements such as subcoolers and cooling fans and so forth as are believed known in the art.

Figures 3 and 3A are cross-sectional views of the compressor assembly of Figure 1 without an additional mass 140 which is described hereinbelow with reference to Figure 7. A reference line ϕ_0 is defined through the axis of rotation D of the drive scroll member 76 and the axis of rotation I of the idler scroll member 78. Since these axes are fixed, the line ϕ_0 is also fixed with reference to the scroll apparatus 20 and may in turn be used as a line from which the angular disposition of the scroll apparatus components may be referenced. A reference position, or point of zero crankangle, of the scroll members is defined when the outer ends of the respective scroll wraps 80 and 100

first make contact with the other respective scroll wrap to define a closed radially outermost first chamber as shown in Figures 3 and 7.

5 The reference line ϕ_i intersects a centerline C which is parallel to and centrally disposed between the axis D of the first scroll 76 and axis I of the second scroll 78. This can be seen more clearly in Figure 4, where 0 defines the offset distance between the axis D and the axis I, and line C is disposed
10 parallel to and equidistant between these axes.

In Figure 3, the center of gravity C_g of the coupling ring 130 is angularly disposed at a predetermined angle ϕ_i to a point on the line ϕ_i to produce a moderating moment. The coupling ring 130,
15 when slidably engaging the extension members 120 and the idler keys 103, comprises means for enhancing the nutational stability of the scroll members by reducing the magnitude of the tipping moment. For convenience of description, the angle ϕ_i of the coupling ring 130
20 is considered to define the line EE upon which the extension members 120 are disposed, while angle ϕ_i refers to the angle at which the line KK is disposed from the line ϕ_i .

When the coupling ring 130 has a center of gravity C_g which is identical with the physical center
25 of the coupling 130, the coupling is positioned at the reference position such that the center of gravity C_g has a predetermined angular position (angle ϕ_i) relative to a point on the reference line ϕ_i and is disposed at a predetermined distance r from the
30 centerline C. This is more clearly shown in Figure 3A, which is an enlargement of the central portion of Figure 3. Those skilled in the art will understand that the angle ϕ_i and the distance r define the
35 disposition of the center of gravity C_g relative to

the reference line when the scroll apparatus is at the reference position shown in Figure 3 and that the actual location of the center of gravity C_g relative to the reference line when the scroll apparatus is at the reference position shown in Figure 3, since the actual location of the center of gravity C_g will change as the scroll apparatus rotates. The center of gravity C_g may follow a cardioidal path or other curvilinear path as the apparatus rotates, depending primarily upon the actual embodiment of the coupling means.

Turning now to Figure 4, the effect of the fluid forces within the scroll wraps 80 and 100 upon the scroll apparatus 20 is more clearly depicted. This figure represents an exaggerated depiction of the effects of these forces. The force components depicted are not intended to indicate actual numerical quantity of a given force, but rather the direction in which the forces act. The scroll wraps themselves, the extension members 120, the coupling 130 and the keys 103 are deleted to permit a clearer view of the forces and the directions in which they act on each scroll.

Figure 4 presents a cross-sectional view of the scroll apparatus 20 taken at the reference position shown in Figure 3 at which there are five chambers C_1 through C_5 . Each of the chambers generates an axial separating force 'a' and a radial separating force 's'. For example, chamber C_1 would generate force vector a_1 as an axial separating force upon the end plate 82 tending to separate the drive scroll end plate 82 from the idler scroll end plate 102, and force vector s_1 , a radial separation force, would act upon the scroll wrap 80 tending to cause a separation from the second scroll wrap 100. Both force vectors

a_1 and s_1 generate a tipping moment about the axis of rotation of the scroll member which tends to cause a turning or tipping of the first scroll member 76 perpendicular to the axis of rotation of the scroll member. The total axial separation force a_d is equal to the vector sum a_1 plus a_2 plus a_3 plus a_4 plus a_5 and the net radial separation force s_d equals the vector sum s_1 plus s_2 plus s_3 plus s_4 plus s_5 . The net effect of the separation forces is to produce a force which is offset from the axis of rotation of the first scroll member 76 due to the fact that the fluid forces and chamber locations and sizes vary. As a result, an instantaneous tipping moment m_t about the axis of rotation of the scroll member is produced. The moment m_t acts upon the scroll member 76 to produce a tipping or nutation about the axis of rotation of the scroll member shown as angle δ_a . Because the chambers are disposed at the same radial and angular location and the fluid forces are the same, but the axes of the scroll members 76 and 78 are offset, the forces in each chamber act to produce a tipping moment m_t for each scroll member 76 and 78 about the respective axis of rotation thereof. Therefore, the separation forces in chambers C1 through C5 act to produce a tipping or nutation of the scroll member 78 shown as angle δ_{a_1} , which may differ from the angle δ_a produced in the scroll member 76 due to differences in the number, types, and sizes of bearing supporting the respective scroll member shafts and other constraints on the respective scroll member end plates. The scroll wraps 80 and 100 will typically separate when δ_{a_1} and δ_a differ.

The above-described calculation of the tipping moments for each scroll member 76, 78 must be repeated for each angular, or crankangle, position of the cycle

of rotation for the respective scroll members 76 and 78. As shown in Figure 4, an axial biasing force acting through axis D is provided by the axial biasing means. This force must be sufficient to exceed the axial separation force, and in addition must supply a scroll tip contact force sufficient to prevent tipping of the scroll member end plate 82 at any given crankangle position. Where the axial separation force exceeds the axial biasing force acting through axis D, tipping due to the tipping moment m_t will occur. Tipping may even occur when the axial separation force is less than the scroll axial biasing force where the biasing force is insufficient to overcome both the separating force and to provide an adequate counteracting moment.

Figure 5 shows an analysis of the instantaneous moments acting upon one of the scroll members 76 or 78 during the rotation of the scroll member with the coupling 130. Crank angle position shown on the horizontal axis of the diagram refers to the angular position of the respective scroll members through one cycle of rotation as measured from the reference position. The exemplary curve representing the instantaneous net moment at each position is roughly sinusoidal for a full rotation of the scroll member.

Figure 6 shows the net instantaneous moments acting upon one of the scroll members 76 or 78 during the rotation of the scroll members with the Cg of the coupling 130 disposed at various angles ϕ_3 , including $\phi_3 = 0$ degrees, $\phi_3 = 30$ degrees, and $\phi_3 = 330$ degrees, where r is constant. It will be appreciated that the net instantaneous moment represents the instantaneous tipping moment at a particular crankangle position as moderated by the moderating moment produced by the coupling. It will be observed

that the graph representing the net instantaneous moments for $\phi_1 = 330$ degrees produces the highest maximum moment. The graph representing the instantaneous moments for $\phi_1 = 0$ degrees produces a lesser maximum moment. When the angle $\phi_1 = 30$ degrees, the lowest maximum moment is produced in the exemplary apparatus. It will be appreciated that these graphs are illustrative and are by way of example only, rather than limiting, since the selected angular disposition of the coupling means center of gravity at the reference position will vary for a particular scroll apparatus and the actual nutation observed in any scroll apparatus 20 depends upon the actual tipping moment at any angular position versus the available counteracting (moderating) moment for preventing nutation.

The method of reducing the net moment of the scroll member by providing a moderating moment with the coupling 130 includes the following steps: the instantaneous tipping moment acting upon a first scroll member is determined for each angular position thereof; the maximum tipping moment together with the angular or crankangle position or range of angular positions at which the maximum tipping moment acts is then determined; a radial (distance r) and angular disposition (angle ϕ_1) of the center of gravity C_g of the coupling ring 130 relative to a point C on the reference line with the scroll members in the reference position which is required to induce a desired moderating moment to moderate the first scroll maximum tipping moment is determined based on the mass of the coupling ring 130; and engaging the first and second scroll members with the coupling with center of gravity C_g disposed at the angle ϕ_1 and the distance r by disposing the extension members 120 on a line EE

at the angle ϕ_1 , and the idler key stubs 103 on a line KK at the angle ϕ_2 . Preferably, the maximum tipping moment, together with the range of crankangle positions at which the maximum tipping moment acts, is also determined for the second scroll member by application of the same methodology so that maximum tipping moment upon the scroll members can be determined and the desired moderating moment for moderating the maximum determined tipping moment of the scroll members may likewise be produced by selective positioning of the coupling center of gravity with the scroll members in the reference position.

As shown in Figures 1 and 7, one or more additional discrete masses m_a 140 may be applied to the coupling 130, either mechanically such as by welding or adhesive. Alternatively the additional mass may be provided integrally at the time of manufacture. The asymmetrically disposed additional mass 140 moves the center of gravity C_g off the axial centerline of the coupling 130 and alters the moderating moment generated by the coupling 130. However, the determination of the angular positioning and amount of the mass m_a is accomplished by determining the tipping moment to be overcome and the crankangle position of that tipping moment, and providing the additional mass m_a on the coupling ring 130 at an angular position ϕ_1 , and distance b from the line C so as to produce the desired moderating moment.

Those skilled in the art will recognise that enhancing the nutational stability of the co-rotating scroll apparatus 20 by optimising placement of the coupling 130 to provide a moderating moment which moderates, or reduces, the scroll member net tipping moment represents a substantial improvement in the

art. No additional components are required in the scroll apparatus 20 so that a simple construction can be obtained together with high operating reliability. Furthermore, the initial cost and operating expense is
5 therefore minimised. Moreover, the scroll apparatus provided is suitable for an inexpensive in mass production, and in use, is relatively compliant and not susceptible to damage. Furthermore, the moderating moment provided by the coupling reduces the
10 required axial biasing force, reducing in turn the frictional losses between the tip scroll wraps 80 and 100 and the end plates 82 and 102, respectively, which in turn reduces the power consumption of the scroll apparatus 20 for a given capacity, permitting the use
15 of smaller and lighter motors 40. In all respects, therefore, a substantial improvement which reduces the initial cost and improves the overall efficiency of the scroll apparatus 20. Furthermore, although the described embodiment is a scroll apparatus 20 useful
20 in refrigeration system applications, it will be undoubtedly appreciated that the features of the scroll apparatus are useful in all applications of the co-rotational scroll apparatus 20, including pumps, expanders, fluid driven engines, and other
25 applications, with like improvement in performance and reduction of expense.

Modifications to the preferred embodiments of the subject invention will be apparent to those skilled in the art within the scope of the claims that follow:

CLAIMS:

1. A co-rotational scroll apparatus comprising:

5 a first scroll member comprising a first scroll end plate, a first scroll wrap including a first upstanding involute portion disposed on said first scroll end plate, and a drive shaft disposed on said first scroll end plate, said first scroll member having an axis of rotation and being subject, in use of the apparatus, to a tipping moment about said axis of rotation which tipping moment varies according to the angle of rotation of said first scroll member;

10 a second scroll member comprising a second scroll end plate, a second scroll wrap including a second upstanding involute portion disposed on said second scroll end plate, said second scroll member having an axis of rotation and being subject, in use of the apparatus, to a tipping moment about said axis of rotation which tipping moment varies according to the angle of rotation of said second scroll member;

20 a coupling means for coupling said first scroll member and said second scroll member, said coupling means being positioned so as to provide, in use of the apparatus, a predetermined moderating moment for enhancing the nutational stability of said scroll apparatus by reducing the magnitude of the maximum said tipping moment to which at least one of said scroll members is subjected; and

25 means for rotating said first scroll member.

30 2. Scroll apparatus as set forth in claim 1, wherein at an angular position of the scroll members at which said first and second scroll wraps make initial contact to define a closed radially outermost chamber therebetween, a center of gravity of said coupling



means has a predetermined angular position relative to a point on a reference line passing through said axes of rotation.

5 3. Scroll apparatus as set forth in claim 2, wherein said center of gravity is radially disposed at a predetermined distance from a centerline of the scroll apparatus.

10 4. Scroll apparatus as set forth in claim 1, 2 or 3, wherein said coupling means comprises a generally symmetrical ring provided with an asymmetrically disposed additional mass.

5. Scroll apparatus as set forth in claim 4, wherein said additional mass has a predetermined angular position relative to a point on said reference line.

15 6. A co-rotational scroll apparatus comprising:
a hermetic shell having a suction pressure portion for containing a suction pressure fluid;
a first scroll member disposed in said suction pressure portion, said first scroll member having a
20 first scroll end plate, a first scroll wrap including a first upstanding involute portion disposed on said first scroll end plate, and a drive shaft disposed on said first scroll end plate, said first scroll member being subject in use of the apparatus to a tipping
25 moment about the axis of said drive shaft which tipping moment varies as the first scroll member rotates;

a second scroll member disposed in said suction pressure portion, said second scroll member having a
30 second scroll end plate, a second scroll wrap including a second upstanding involute portion



disposed on said second scroll end plate, and an idler shaft disposed on said second scroll end plate, said second scroll member being subject in use of the apparatus to a tipping moment about the axis of said idler shaft which tipping moment varies as the second scroll member rotates;

coupling means for drivingly coupling said first scroll member and said second scroll member, said coupling means being positioned such that at an angular position of said scroll members at which said first and second scroll wraps make initial contact to define a closed radially outermost chamber therebetween, a center of gravity of the coupling means has a predetermined angular position relative to a point on a reference line passing through the respective axis of said drive and idler shafts to produce, in use of the apparatus, a moderating moment which enhances the nutational stability of said scroll apparatus by acting in opposition to and thereby reducing the tipping moment of at least one of said scroll members;

means for rotatably supporting said idler shaft in said suction portion of said hermetic shell; and

means for rotating said drive shaft.

7. Scroll apparatus as set forth in claim 6, wherein the center of gravity of said coupling means is radially disposed at a predetermined distance from a centerline which is parallel to and equidistant between the respective axis of said drive and idler shafts.

8. Scroll apparatus as set forth in claim 7, wherein said coupling means comprises a generally symmetrical coupling ring provided with an asymmetrically disposed



additional mass.

9. Scroll apparatus as set forth in claim 8, wherein said additional mass has a predetermined angular position relative to a point on said reference line.

5 10. Scroll apparatus as set forth in claim 9, wherein said additional mass is disposed at a predetermined distance from said centerline.

10 11. Scroll apparatus as set forth in claim 8, 9 or 10, wherein said additional mass is a discrete mass mechanically applied to said coupling ring.

12. Scroll apparatus as set forth in claim 8, 9 or 10, wherein said additional mass is integral to said coupling ring.

15 13. A refrigeration system for circulating refrigerant in closed loop connection, said system comprising:

a condenser for condensing refrigerant to liquid form;

20 an expansion device for receiving liquid refrigerant from said condenser and expanding the refrigerant;

an evaporator for receiving the refrigerant from said expansion device and evaporating the refrigerant to vapor form; and

25 a compressor for receiving the refrigerant from the evaporator, compressing the refrigerant, and sending the refrigerant to the condenser, said compressor comprising:

30 a hermetic shell having a suction pressure portion for containing a suction pressure fluid;



a first scroll member disposed in said suction pressure portion, said first scroll member having a first scroll end plate, a first scroll wrap including a first upstanding involute portion disposed on said first scroll end plate, and a drive shaft having an axis of rotation and being disposed on said first scroll end plate, said first scroll member being subject in use of the apparatus to a tipping moment about said axis of rotation which tipping moment varies as the first scroll member rotates;

a second scroll member disposed in said suction pressure portion, said second scroll member having a second scroll end plate, a second scroll wrap including a second upstanding involute portion disposed on said second scroll end plate, and an idler shaft having an axis of rotation and being disposed on said second scroll end plate, said second scroll member being subject in use of the apparatus to a tipping moment about said axis of rotation of the idler shaft which tipping moment varies as the second scroll member rotates;

coupling means for drivingly coupling said first scroll member and said second scroll member, said coupling means being disposed such that at an angular position of said scroll members at which said first and second scroll wraps make initial contact to define a closed radially outermost chamber therebetween, a center of gravity of the coupling means has a predetermined angular position relative to a point on a reference line passing through the respective axis of said drive and idler shafts to produce a moderating moment which enhances the nutational stability of said scroll apparatus by acting in opposition to and thereby reducing the magnitude of the maximum said tipping moment acting on a selected one of said scroll



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members;

means for rotatably supporting said idler shaft
in said suction portion of said hermetic shell; and

means for rotating said first scroll drive shaft.

5 14. A method of enhancing the nutational stability of
a co-rotational scroll apparatus having a first scroll
member and a second scroll member which are in
interleaving engagement, said scroll members each
being subject, in use of the apparatus, to a tipping
10 moment about the respective axis of rotation thereof
the method comprising the steps of:

 determining for at least one of said scroll
members the maximum said tipping moment to which that
scroll member is subject and a rotational position of
15 that scroll member at which said maximum tipping
moment occurs; and

 engaging said first scroll member and said second
scroll member with a coupling, said coupling being
disposed such that during said use, the moment
20 produced by said coupling due to the location of its
centre of gravity reduces said maximum tipping moment.

 15. A method as claimed in claim 14, including the
steps of determining for the other of said scroll
members the maximum tipping moment to which that
25 scroll member is subject and a rotational position of
said other scroll member at which said maximum tipping
moment occurs; and

 determining the maximum determined tipping moment
of said scroll members, wherein in said step of
engaging said first and second scroll members with a
30 coupling, the coupling is disposed such that said
moment produced by the coupling reduces said maximum
determined tipping moment.



16. A method of enhancing the nutational stability of a co-rotational scroll apparatus having a driven scroll member and an idler scroll member, said driven scroll member having an axis about which it rotates through a cycle of angular positions and including a first involute scroll wrap, said idler scroll member having an axis about which it rotates through said cycle of angular positions and including a second involute scroll wrap in interleaving engagement with said first scroll wrap, and said driven scroll member and said idler scroll member being subject during operation of the apparatus to a respective tipping moment about the respective said axis of rotation thereof, said method comprising the steps of:
- 5 determining a reference position of said scroll members at which said first and second scroll wraps form a first chamber;
 - 10 determining at least for the idler scroll member, the instantaneous tipping moment to which said scroll member is subject at each said angular position;
 - 15 determining at least for the idler scroll member the maximum of said instantaneous tipping moments and the angular position of the scroll member relative to said reference position when said maximum tipping moment occurs;
 - 20 determining for said reference position an angular position relative to a point on a reference line passing through the respective axis of rotation of said driven and idler scroll members at which to position a mass for producing a moderating moment for counteracting at least said maximum tipping moment to which said idler scroll member is subject; and
 - 25 engaging said driven scroll member and said idler scroll member with a coupling means having a predetermined mass such that at said reference
 - 30
 - 35



36.

position of the scroll members, a center of gravity of the coupling means is disposed at said angular position relative to a point on said reference line for producing said moderating moment during operation of the apparatus.

5

17. The method as set forth in claim 16, including the further steps of:

determining the instantaneous tipping moment to which said driven scroll member is subject at each said angular position;

10

determining the maximum of said instantaneous tipping moments to which the driven scroll member is subject and the angular position of the driven scroll member relative to said reference position when said maximum tipping moment occurs.

15

18. The method as set forth in claim 16 or 17, including the further step of determining for said reference position an angular position relative to a point on said reference line at which to position an additional mass on said coupling for producing a moderating moment.

20

19. A co-rotational scroll apparatus having coupling means coupling first and second scroll members thereof for concurrent rotation about parallel spaced axes, the mass of the coupling being disposed such that it produces a moment opposing the respective tipping moment about the respective said axis of at least one of the scroll members at a crankangle where said tipping moment is a maximum.

25

20. A co-rotational scroll apparatus substantially as herein described with reference to Figs. 1, 3, 4 and

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37.

7 of the accompanying drawings.

21. A method of coupling co-rotational scroll members substantially as herein described with reference to the accompanying drawings.
