

BALL VALVE

TECHNICAL FIELD

[0001] The disclosure generally relates to the field of fluid flow control devices more particularly to design and implementation of ball valves.

5 BACKGROUND

[0002] Boreholes are drilled into subterranean formations to enable withdrawal and injection of fluids such as hydrocarbon fluids in the case of withdrawal and injection fluids in the case of injection. During drilling and production phases of hydrocarbon recovery, various procedures are performed that involve temporarily isolating fluid flows into or out of a formation such as via
10 a wellbore fluid conduit. Such procedures may include flow control operations, completion operations, and/or intervention operations. Various types of valves, such as ball valves, may be deployed in a fluid flow control system and used during downhole operations to control the flow of fluid through one or more wellbore conduits. Ball valves generally include a valve seat for receiving a valve stopper, sometimes referred to as a ball stopper, having a through hole flow
15 port passing therethrough. A ball valve is opened and closed in a quarter turn procedure in which the valve stopper through hole is either aligned with the fluid flow path (open position) or turned approximately 90° such that one or both closed faces of the valve stopper block fluid flow (closed position).

[0003] With the ball valve in the closed position, fluid flow is blocked by a seal formed by the
20 seating of a closed face of the valve stopper in a valve seat. A typical valve seat may comprise a ring surface that ideally makes close contact with the corresponding ring-shaped portion of the ball shaped valve stopper. The seating is typically accomplished at least in part by seating actuation means such as spring and/or hydraulic means that push, pull, or otherwise bias the valve seat toward the valve stopper to form the seal when the valve stopper is seated in the
25 closed position. Ball valves are primarily utilized as flow gates that either allow or prevent fluid flow. The structure of ball valves in terms of material composition and configuration of constituent components (e.g., valve stopper, valve seat) may have significant operational effects. For example, a metal-to-metal ball valve configuration utilizes metal valve seats as well as a metal valve stopper to render the sealing surfaces of the ball valve more resistant to damage by
30 pressure transients during valve open/close transitions and chemicals and/or solid particles.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Embodiments of the disclosure may be better understood by referencing the accompanying drawings.

5 [0005] **FIG. 1** is a schematic view depicting a well system that includes one or more ball valve assemblies configured in accordance with the disclosed embodiments;

[0006] **FIG. 2A** is a cross-section diagram depicting implementation of a through ball valve in accordance with some embodiments;

[0007] **FIG. 2B** is a front profile illustrating surface features of a closed face with respect to internal cross-section features of the ball valve depicted in **FIG. 2A**;

10 [0008] **FIGS. 3A-3C** are perspective and side profile views depicting a ball valve stopper configured in accordance with some embodiments;

[0009] **FIG. 3D** is a side profile view illustrating a ball valve stopper configured in accordance with some embodiments;

15 [0010] **FIG. 3E** is a perspective image with shaded coding depicting the deformation profile across a closed face of a conventional ball valve stopper;

[0011] **FIG. 3F** is a perspective image with shaded coding illustrating the deformation profile across a closed face of a ball valve stopper configured in accordance with some embodiments;

[0012] **FIG. 4** is a perspective image depicting a ball valve stopper configured in accordance with some embodiments;

20 [0013] **FIG. 5** is a perspective image illustrating a ball valve stopper configured in accordance with some embodiments;

[0014] **FIG. 6** is a perspective image depicting a ball valve stopper configured in accordance with some embodiments;

25 [0015] **FIGS. 7A-7C** are perspective and side images illustrating a ball valve stopper configured in accordance with some embodiments; and

[0016] **FIG. 7D** is a side image depicting modified closed face contouring of a ball valve stopper following application of hydraulic pressure in accordance with some embodiments.

DESCRIPTION OF EMBODIMENTS

[0017] The description that follows includes example systems, methods, techniques, and program flows that embody embodiments of the disclosure. However, it is understood that this disclosure may be practiced without some of these specific details. In other instances, well-known instruction instances, protocols, structures and techniques have not been shown in detail in order not to obfuscate the description.

[0018] Overview

[0019] The disclosure is directed to a ball valve and components therein for controlling the flow of a fluid, for example in a subterranean wellbore. A seal may be formed in a ball valve having a contact pressure in excess of the fluid pressure being sealed against. A ball valve includes a ball valve stopper that is spherically contoured and includes a flow port that permits fluid flow through the ball valve when the ball valve is in an open position. The ball valve stopper includes a solid and spherically contoured closed face that is seated against a valve seat to form a seal against fluid pressure when the ball valve is in a closed position. In high-pressure contexts, the force applied to the closed face may cause deformations that due to the non-uniform internal structure of the ball valve stopper causes gaps in the seal between the closed face and the valve seat. Embodiments disclosed herein include a ball valve assembly including a valve stopper rotatable about a rotation axis and comprising a closed face that is orthogonally disposed with respect to a flow port through the valve stopper. The ball valve assembly further includes a valve seat having an annular seating surface that contacts an annular sealing area on the closed face when the valve stopper is rotated to the valve closed position. The valve stopper includes a material discontinuity volume formed behind the closed face within at least a portion of a circular cross-section area of the valve stopper bounded by the annular sealing area.

[0020] Example Illustrations

[0021] **FIG. 1** is a schematic view depicting a well system **100** that includes a ball valve assembly **115** configured in accordance with the disclosed embodiments. Well system **100** includes a well head **106** that is positioned on a terrain surface **104** and extends over a wellbore **114** that penetrates a subterranean formation **102** for the purpose of recovering hydrocarbons. Well system **100** further includes a wellbore tubular string **120** comprising a wellbore tubular and a ball valve assembly **115**. Wellbore tubular string **120** may be lowered into wellbore **114** for a variety of production and treatment procedures throughout the life of well

system **100**. **FIG. 1** illustrates wellbore tubular string **120** configured as a production tubing string that includes a packer **140** disposed within wellbore **114**. The wellbore tubular string **120** comprising the ball valve assembly **115** is equally applicable to any type of wellbore tubular string installed within wellbore **114** and utilized for procedures requiring fluid isolation from above or below ball valve assembly **115**. Example categories of wellbore tubular strings in which ball valve assembly **115** may be installed include production and injection tubing, drill pipe, casing, rod strings, and coiled tubing.

[0022] Wellhead **106** comprise various drilling and/or production related components such as motors, winches and associated equipment for positioning wellbore tubular string **120** within wellbore **114** and performing various operations relating to production and injection as well as maintenance operations. Regardless of the type of operational environment in which ball valve assembly **115** is deployed, ball valve assembly **115** is configured to control the flow of fluid through a tubular or conduit, including situations in which the fluid flow source originates downstream from either side and/or both sides of ball valve assembly **115**. As utilized herein “ball valve assembly” may be used interchangeably with “ball valve.” A ball valve assembly such as ball valve assembly **115** includes multiple components including a valve stopper and one or more valve seats disposed between at least one downstream port (i.e., port from which fluid flow originates) and at least one upstream port (i.e., port to which fluid flows when the ball valve is open). In some embodiments, ball valve assembly **115** may include a valve body that houses the valve stopper and valve seat components.

[0023] The use of ball valve assembly **115** as disclosed herein may allow for control of the flow of a fluid into, out of, and through wellbore tubular string **120**. In some embodiments, one or more ball valves such as ball valve **115** may be deployed within wellbore tubular string **120** to control the flow of fluids within various zones of wellbore **114**. In order to control the flow of a fluid within wellbore **114**, ball valve assembly **115** may be actuated from an open, flow through position to a closed, flow stop position and from the closed position to the open position to selectively allow or prevent fluid flow to, from, and/or within wellbore tubular string **120**. While **FIG. 1** depicts ball valve assembly **115** deployed in a subterranean wellbore environment, other embodiments may utilize similar ball valves assemblies for other fluid flow control applications involving substantial differential pressures across a ball valve assembly such as may occur in pipelines, refineries, chemical plants, manufacturing facilities, water treatment/storage/supply, etc.

[0024] **FIG. 2A** is a cross-section diagram depicting implementation of a ball valve **200** in accordance with some embodiments. Ball valve **200** comprises a valve body **202** that houses a ball-type valve stopper **206** within a cavity **204**. Cavity **204** and the components contained therein are positioned between an upstream flow port **208** and a downstream flow port **210**. Ball valve **200** is depicted in **FIG. 2A** in the valve closed position in which a closed face **214** of valve stopper **206** is facing into upstream flow port **208** and a closed face **216** is facing into downstream flow port **210**. Valve stopper **206** comprises a spherical contoured body member fabricated of a relatively hard and inelastic material such as a stainless steel alloy. Orthogonal to closed faces **214** and **216**, a flow port **212** is formed as a cylindrical conduit enabling fluid flow from downstream port **210** to upstream port **208** when ball valve **200** is in the valve open position with valve stopper **206** rotated by 90° from the depicted closed position. Ball valve **200** can be moved between the open and depicted closed positions by rotating valve stopper **206** about a rotation support member **218** that is aligned orthogonally to flow port **212** and closed faces **214** and **216**. Rotation support member **218** may comprise an attached or integral component to valve stopper **206** and may be configured as an extending cylindrical hub that when secured within a suitable guide bearing (not depicted) provides linear position retention as well as enabling rotation of valve stopper **206**.

[0025] In the depicted embodiment, ball valve **200** is a single seat valve comprising a valve seat **220** that is linearly actuated to press against the downstream closed face **216** of valve stopper **206**. At the end of valve seat **220** is an annular seat surface that is depicted as the curved end surface end of valve seat **220** that contacts closed face **216**. Valve seat **220** is actuated by one or more springs **222** that apply a force that pushes the annular seating surface of valve seat **220** against an annular sealing area **224** on closed face **216**. The contact between the annular seating surface of valve seat **220** and the corresponding annular sealing area **224** provides a seal on closed face **216** to prevent fluid leakage. Annular sealing area **224** circumferentially bounds a spherically contoured (circular in cross-section) sealing area **225** on closed face **216**. Together, annular sealing area **224** and spherical sealing area **225** comprise an overall circular/spherical fluid seal area that is bounded by the outer edge of annular sealing area **224**. **FIG. 2A** illustrates components of ball valve **200** that directly or indirectly provide a fluid sealing function. While not depicted in **FIG. 2A**, ball valve **200** may also include components (e.g., a threaded connection) located above or below ball valve **200** to allow ball valve **200** to be disposed within and/or coupled to a wellbore tubular (e.g., of wellbore tubular string **120** in **FIG. 1**) and/or other

wellbore components (e.g., production subs, downhole tools, screens, etc.), for example to form a workstring, production string, conveyance string, etc.

[0026] **FIG. 2B** is a front profile view illustrating surface features of closed face **216** with respect to internal cross-section features of ball valve **200** depicted as broken lines. In the depicted embodiment, valve stopper **206** is spherically contoured, comprising a truncated sphere having planar surfaces **211** and **213** on opposite sides of the sphere. Planar surfaces **211** and **213** include rotation bearings **218a** and **218b**, respectively, (e.g., cylindrical members) extending outwardly therefrom. Flow port **212** is depicted in broken line shadow form to depict the mutually orthogonal orientation of closed face **216** with respect to flow port **212** and rotation bearings **218a** and **218b**. **FIG. 2B** depicts the regions on closed face **216** that are exposed to pressure from hydraulic forces as well as force applied by the seat surface of valve seat **220** as linearly urged by springs **222**.

[0027] Referring to **FIG. 2B** in conjunction with **FIG. 2A**, in the depicted valve closed position, substantial pressure may be applied across the portion of closed face **216** within the circumferential boundary of annular sealing area **224** that forms the overall fluid seal. The hydraulic pressure may be applied by a fluid **226** within downstream flow port **210** originating from a pressurized source (not depicted). The pressure may be a varying pressure during rotation of valve stopper **206** to close and/or open ball valve **200**. With ball valve **200** in the closed position, pressure from springs **222** is applied via the seating surface of valve seat **220** to annular sealing area **224**. In some embodiments, valve seat **220** may include alternate or additional linear actuation means such as a hydraulically controlled boost piston component. In such embodiments, the pressure applied by the seating surface of valve seat **220** may correspond to hydraulic pressure such as hydraulic pressure from downstream flow port **210**.

[0028] The contact of the annular seating surface of valve seat **220** with annular sealing area **224** forms a ring shaped seal preventing fluid leakage at or proximate to closed face **216**. Given the considerable fluid pressures that may be encountered in some applications, the contact between the seating surface of valve seat **220** and annular sealing area **224** must be relatively uniform such that there are no significant gaps in the resultant seal. Some ball valves use elastic materials such as polymers to provide closer and more uniform contact to form the seal. However, some fluid flow control applications, such as controlling flows of downhole fluids in a well system, entail environmental conditions that require harder and less elastic materials be used to form ball valve seals. For example, downhole flow control environments may include

high hydraulic pressures applied from downstream that may result in pressure transients during the closing and/or opening of a ball valve that may damage softer and/or relatively elastic materials.

[0029] Metal-to-metal (m-t-m) seating may be used in which the annular seating surface of valve seat **220** and the closed surface **116** of valve stopper both comprise relatively hard and inelastic metals or metallic alloys. Such m-t-m ball valve configurations may locate the valve seat below (downstream) to avoid sealing discontinuities that may result from debris fallout that may accumulate above (upstream) a valve stopper when the ball valve is closed as depicted in **FIG. 2A**. However, an m-t-m ball valve such as ball valve **200** may be subject to pressure effects that may alter the surface contour of closed surface **116**, resulting in contact gaps that comprise the seal between the annular seating surface of valve seat **220** and annular sealing area **224**.

[0030] Within annular sealing area **224**, spherical sealing area **225** provides a majority of the overall fluid sealing between downstream flow port **210** and upstream flow port **208**. While the pressure gradient is relatively uniform over spherical sealing area **225**, the resistance of closed surface **216** including spherical sealing area **225** and annular sealing area **224** to deformation may be compromised at least in part by non-uniformities in the internal structure of valve stopper **206** particularly relating to flow port **212**. For instance, **FIGS. 2A** and **2B** depict the internal material non-uniformity caused by flow port **212** that results in greater metallic material support nearer the support bearings **218a** and **218b** and lesser material support within the cross-section profile of flow port **212**. Portions of spherical sealing area **225** and annular sealing area **224** may therefore be subject to greater surface deformation at materially “thinner” regions such as along or proximate to the edges of flow port **212**. The deformation that would otherwise occur within spherical sealing area **225** would contribute to overall reduction in surface uniformity across closed face **216** to include annular sealing area **224**, thereby creating gaps in the seal between annular sealing area **224** and the annular seating surface of valve seat **220**.

[0031] To address and effectively counteract the reduced interior material support, valve stopper **206** includes a material discontinuity volume **230** as depicted in **FIG. 2A**. Material discontinuity volume **230** is contoured and located in a manner as to maximize uniform deformation of annular sealing area **224** by maximizing circular uniformity of the deformation of spherical sealing area **225** as well as annular sealing area **224** itself. As disclosed herein, a material discontinuity volume is essentially a volume located within the generally spherical contour of a ball valve stopper such as a volume having a contour that may be described as an

open or closed hole, channel, cavity, pocket, recess, groove, etc. Material discontinuity volume **230** may comprise a volume (e.g., channel) that is either empty (e.g., a channel-contoured void) within valve stopper **206** or comprises a material having significantly different elasticity properties and/or deformation hardness as the metallic material that the main structure (e.g., closed faces) of valve stopper **206** is comprised of. Based on or in addition to volume contouring and material content, the location of material discontinuity volume **230** may significantly affect the circular uniformity of deformation of regions of closed face **216** including spherical sealing area **225** and annular sealing area **224**.

[0032] As depicted in **FIG. 2A**, material discontinuity volume **230** is disposed behind one or more portions of closed face **216** including an overall fluid seal area formed by spherical sealing area **225** and annular sealing area **224**. For example, material discontinuity volume **230** may comprise a pair of open channels that run substantially parallel to the direction of flow port **212**. The depth of the channel may be uniform or may vary based on proximity to materially thicker or thinner cross-section regions of valve stopper **206**. In **FIG. 2B** for instance, a varying depth of the channel of which material discontinuity volume **230** is comprised is indicated by the contour formed by internal edges **233** of material discontinuity volume **230**. As shown, the depth of the channels varies at different circumferential points based on the position of each of the points to a centerline flow axis **219** of flow port **212**. In some embodiments, such as shown in **FIG. 2B** by the arced internal edges **233** defining the bottoms of the channels, the depth at each point of the channels increases at circumferential points around closed face **216** that are further from an axial centerline of flow port **212**.

[0033] **FIGS. 3-7** depict ball valve stoppers configured in accordance with some embodiments and may be utilized as ball valve stoppers for the ball valves depicted in **FIGS. 1, 2A, and 2B**. **FIGS. 3A-3C** are perspective and side profile views depicting a ball valve stopper **300** configured in accordance with some embodiments. Ball valve stopper **300** comprises a spherical contoured metallic body that includes a rotation support member **302**, such as a trunnion support, that is aligned orthogonally with respect to a flow port **304**. Orthogonally aligned with respect to flow port **304** and rotation support member **302** is a closed face that includes a fluid seal area **306** that is bounded by an annular sealing area **308** against which a valve seat is pushed in a ball valve assembly when the assembly is in the closed valve position. Ball valve stopper **300** further includes a material discontinuity volume in the form of a pair of open channels **310** that run substantially in parallel to the flow port **304**. As shown, each of open channels **310** is positioned behind a semi-circular portion of the fluid seal area within annular sealing area **308**. Each of

open channels **310** is further positioned between a respective one of the diametrically opposed rotation support members **302** and at least a portion of fluid seal area **306**. Open channels **310** are each straight line channels that vary in depth and consequently in cross-section area at various points based on the distance between an outer edge point of the channel (i.e., the outer circumferential point) and the centerline axis of flow port **304**. In the depicted embodiment, the depth and cross-section area of channels **310** at each point along the outer circumferential edges **312** of channels **310** varies inversely with respect to a distance between each outer circumferential point and the centerline axis of the flow port.

[0034] The void channel volumes embodied by open channels **310** result in a more circularly uniform pressure resistance around the circular perimeter of annular sealing area **308**. For example, **FIG. 3E** is a perspective image with shaded coding depicting the deformation profile across a closed face of a conventional ball valve stopper **340**. As shown by the differential shade coding, the closed face is deformed in a non-uniform manner that is greatest along a rectangular area over the depicted flow port. In contrast, **FIG. 3F** is a perspective image with shaded coding illustrating the deformation profile across a closed face of a ball valve stopper **350** configured in accordance with one or more embodiments of the present disclosure. As shown by the differential shade coding, the pressure resistance balancing provided by a material discontinuity volume such as represented by open channels **310** results in closed face deformation that is substantially more circularly uniform. The difference in circular uniformity of the closed face deformation may translate to higher differences along an annular sealing area such as from 0.008"-0.010" for **FIG. 3E** and lower differences such as approximately 0.003" for **FIG. 3F**.

[0035] In some embodiments, the material discontinuity volume may comprise a cavity or channel that is not a void or space and instead contains a filler material that provides the pressure resistance offset/balance function while maintaining greater overall structural strength. For example, **FIG. 3D** is a side profile view illustrating ball valve stopper **300** configured to include closed or filled channels **312** disposed behind fluid seal area **306**. In some embodiments, the material contained in channels **312** may be a metallic and/or elastomeric material having different properties in terms of reaction to an applied pressure than the material of which the body of ball valve stopper **300** is fabricated. For example, the material in channels **312** may comprise a metal, alloy, elastomeric, or polymer having a lower modulus of elasticity and/or a lower indentation hardness than the modulus of elasticity or indentation hardness of material of which the body of ball valve stopper **300** is fabricated, such as another metal, alloy, elastomeric or polymer of which the body of ball valve stopper **300** may be fabricated.

[0036] **FIGS. 4-6** depict differently configured ball valve stoppers configured in accordance with some embodiments. **FIG. 4** is a perspective view depicting a ball valve stopper **400** as including a material discontinuity volume in the form of a pair of open channels **410** that run substantially in parallel to a flow port **404**. As shown, each of open channels **410** is positioned
5 between a respective one of a pair of rotation support members **402** and at least a portion of a fluid seal area **406** of a closed face of ball valve stopper **400**. In the depicted embodiment, open channels **410** are each straight line channels that vary in depth at various points based on the distance between an outside point of the channel (i.e., the outer circumferential point) and the centerline axis of flow port **404**. In contrast to open channels **310**, open channels **410** are formed
10 using multiple material layers.

[0037] **FIG. 5** is a perspective view depicting a ball valve stopper **500** as including a material discontinuity volume in the form of a pair of open channels **510** that run substantially in parallel to a flow port **504**. As shown, each of open channels **510** is positioned between a respective one of a pair of rotation support members **502** and at least a portion of a fluid seal area **506** of a
15 closed face. In the depicted embodiment, open channels **510** are each straight line channels that vary in depth at various points based on the distance between an outside point of the channel (i.e., the outer circumferential point) and the centerline axis of flow port **504**. In contrast to open channels **310** and **410**, open channels **510** extend through and perforate the inner surface of flow port **504**.

[0038] **FIG. 6** is a perspective view depicting a ball valve stopper **600** as including a material discontinuity volume in the form of a pair of open pockets **610** formed underneath an arched or otherwise curved portion of a fluid seal area **606** within a closed face and that are aligned with each of a pair of rotation support members **602**. As shown, each of open pockets **610** is
20 positioned between a respective one of rotation support members **602** and at least a portion of fluid seal area **606**. In the depicted embodiment, and in contrast to the straight-line channels in **FIGS. 3, 4, and 5**, open pockets **610** are curved volumes that may vary in depth at various points based on the distance between an outside point of the channel (i.e., the outer circumferential point) and the centerline axis of flow port **604**.

[0039] **FIGS. 7A-7C** are perspective and side images illustrating a ball valve stopper **700**
30 configured in accordance with some embodiments. Ball valve stopper **700** comprises a spherical contoured metallic body that includes a rotation support member **702** that is aligned orthogonally with respect to a flow port **704**. Orthogonally aligned with respect to flow port **704** and rotation

support member **702** is a closed face that includes a fluid seal area **706** that is bounded by an annular sealing area **708** against which a valve seat is pushed in a ball valve assembly when the assembly is in the closed valve position. Ball valve stopper **700** further includes a material discontinuity volume in the form of a circumferential channel **710** that is disposed behind a

5 portion of closed face **706** and circumferentially bounds fluid seal area **706** of a closed face of ball valve stopper **700**. As shown particularly in the cutaway view of **FIG. 7C**, circumferential channel **710** is a slot channel having an outer circular and inner elliptical contour. Along the elliptical contour, the depth in the slot channel at each point on the circumference of fluid seal area **706** varies inversely with respect to a distance from the point to a centerline axis of flow

10 port **704**. **FIG. 7D** is a side image depicting fluid seal area **706** having been deformed in a circularly uniform manner following application of hydraulic pressure to fluid seal area **706** in accordance with some embodiments.

Example Embodiments:

[0040] Embodiment 1: a ball valve stopper comprising: a spherical contoured body comprising

15 a substantially inelastic first material and having a flow port; a closed face of the spherical contoured body that is orthogonal with respect to the flow port and includes a fluid seal area; a rotation support member aligned orthogonally to the flow port and the fluid seal area; and a material discontinuity volume disposed behind the closed face of the spherical contoured body.

[0041] Embodiment 2: the ball valve stopper of Embodiment 1, wherein the material

20 discontinuity volume is at least partially disposed behind the fluid seal area.

[0042] Embodiment 3: the ball valve stopper of Embodiments 1-2, wherein the material discontinuity volume includes a channel in the spherical contoured body that either comprises a void or contains a second material having a different modulus of elasticity than a modulus of elasticity of the first material.

[0043] Embodiment 4: the ball valve stopper of Embodiments 1-3, wherein the first material is

25 metallic.

[0044] Embodiment 5: the ball valve stopper of Embodiments 1-4, wherein the second material has a lower modulus of elasticity than a modulus of elasticity of the first material.

[0045] Embodiment 6: the ball valve stopper of Embodiments 1-5, wherein the material discontinuity volume is disposed between at least a portion of the fluid seal area and the rotation support member.

5 [0046] Embodiment 7: the ball valve stopper of Embodiments 1-6, wherein the material discontinuity volume comprises a channel and wherein a cross-section area of the channel varies based on the proximity of the cross-section area to a centerline axis of the flow port.

[0047] Embodiment 8: the ball valve stopper of Embodiments 1-7, wherein the cross-section area of the channel varies inversely with respect to a distance between the cross-section area and the centerline axis of the flow port.

10 [0048] Embodiment 9: the ball valve stopper of Embodiments 1-8, wherein the material discontinuity volume comprises a slot channel disposed circumferentially around the fluid seal area.

[0049] Embodiment 10: the ball valve stopper of Embodiments 1-9, wherein a depth of the slot channel at each point on the circumference of the slot channel varies inversely with respect to a
15 distance from the point to a centerline axis of the flow port.

[0050] Embodiment 11: the ball valve stopper of Embodiments 1-10, wherein said rotation support member comprises a diametrically opposing pair of trunnion support members, wherein the material discontinuity volume comprises a pair of linear channels each formed between a respective one of the trunnion support members and the closed face.

20 [0051] Embodiment 12: A ball valve assembly comprising: a valve stopper rotatable about a rotation axis and comprising a closed face that is orthogonally disposed with respect to a flow port through the valve stopper; a valve seat having an annular seating surface that contacts an annular sealing area on the closed face when the valve stopper is rotated to a valve closed position; and wherein the valve stopper includes a material discontinuity volume formed behind
25 the closed face within at least a portion of a circular cross-section area of the valve stopper bounded by the annular sealing area.

[0052] Embodiment 13: the ball valve assembly of Embodiment 12, further comprising a rotation support member centrally aligned on the rotation axis, wherein the material discontinuity volume comprises a linear channel between the rotation axis and the annular sealing area.

[0053] Embodiment 14: the ball valve assembly of Embodiment 12, wherein the material discontinuity volume comprises a channel disposed circumferentially around a fluid seal area within the closed face and varies in cross-section area.

5 [0054] Embodiment 15: the ball valve assembly of Embodiments 12-14, wherein the channel comprises a void.

[0055] Embodiment 16: the ball valve assembly of Embodiments 12-14, wherein the valve stopper comprises a first metallic material, and wherein the channel contains a second material having a lower modulus of elasticity than the first metallic material.

10 [0056] Embodiment 17: the ball valve assembly of Embodiments 12-16, further comprising an actuator configured to press the valve seat in contact with the annular sealing area.

[0057] Embodiment 18: the ball valve assembly of Embodiments 12-17, further comprising a body housing a valve cavity disposed between an upstream flow port and a downstream flow port and within which said valve stopper rotates.

15 [0058] Embodiment 19: the ball valve assembly of Embodiments 12-18, wherein said valve seat and the annular sealing area are disposed within the downstream flow port when the valve stopper is rotated to the valve closed position.

20 [0059] Embodiment 20: the ball valve assembly of Embodiments 12-19, wherein the material discontinuity volume comprises a slot channel disposed circumferentially around a fluid seal area within the closed face, and wherein a depth of the slot channel at each point on the circumference of the slot channel varies inversely with respect to a distance from the point to a centerline axis of the flow port.