transfer drive element **58** of the third articulation **26** of the haptic interface **10**. Referring first to **FIGS. 1 and** 4A-4B, the cable drive transmission for the third articulation **26** spans a distance from the hub of the second element **18**, along the extension **24** thereof, to a hub of the third element **22**. As mentioned hereinabove, the actuator for the third articulation **26** is disposed remotely, proximate the actuator for the second articulation **20** in the hub thereof, to minimize the size and the weight of the cantilevered third articulation **26**. Accordingly, the second articulation hub is configured with two rotatable components nested on a common axis, namely the second axis, B, as will be discussed in greater detail hereinbelow.

[**0040**] Referring once again to **FIG.** 2D, the transfer drive element **58** is journaled for rotation about the second axis B. A cable **348** is fixed to the element **58** at a ground location **350** and circumscribes the element **58** in a clockwise direction. The cable **348** wraps an actuator capstan **356** disposed substantially tangentially to the circumference before wrapping several times around a clutch post **352**. Thereafter, the cable is attached to a spring **354** in tension which is grounded to the element **58** at **250**. Since the actuator (not depicted) is fixed to the first element **14**, as the actuator rotates the capstan **356**, the transfer drive element **58** is caused to rotate about second axis B.

[**0041**] A reverse side of the transfer drive element **58** is depicted in **FIG.** 2E and employs a second automatic cable tensioning device **446** for transferring the rotation of the drive element located in the hub of the second element **18** to the third articulation **26**. A first rigid transfer drive rod **60** grounded to the third element **22** is crimped or otherwise attached to a tungsten or stainless steel cable **448** proximate the drive element **58**. The cable **448** circumscribes a central hub of the drive element **58** in a clockwise direction. The cable **448** wraps several times around a clutch post **452** before being attached to a spring **454** in tension which is grounded to the element **58** at **450**. As the actuator rotates the transfer drive element **58** about axis B, as discussed with respect to **FIG. 2D** hereinabove, the rotational motion of the drive element **58** is transformed into linear motion of the transfer drive rod **60**. A second transfer drive rod grounded between the transfer drive element **58** and the third element **22** completes the third axis drive, as will be discussed in greater detail hereinbelow.

[**0042**] Instead of simply wrapping a cable around an actuator capstan one or more times and providing tension to the cable to reduce the likelihood of slippage, the cable may be positively grounded to the capstan to ensure there is no slippage relative thereto. **FIG. 3A** is a schematic cross-sectional view of a grounded actuator capstan **456** for use in the cable drives of the haptic interface **10** in accordance with an embodiment of the present invention. The grounded capstan **456** may be used with conventional cable drives or advantageously with the automatic cable tensioning device **46**.

[**0043**] The generally cylindrical capstan **456** forms a centrally disposed bore **62** sized to receive an actuator shaft **64**. The capstan **456** may be secured to the shaft **64** by bonding, mechanical fastening, or any other suitable method. A keyway, spline, or other anti-rotation feature may also be provided, if desired. A generally centrally radially disposed aperture **66** is provided in the capstan **456**, the aperture **66** sized to permit passage therethrough of a double portion of a drive cable **558**. The shaft may be D-shaped or have a flat or groove formed therein as shown generally at **68**.

[**0044**] At assembly, two lengths of cable **558** are passed through the aperture **66** in the capstan **456** and knotted together as shown generally at **70**. Used herein, knotting refers to the process of forming a bulge in a length of cable. This may be achieved by tying the two lengths together or by using a device which crimps the two lengths together in a bead. In the former method, the knot is formed by the cables themselves and in the latter case, the knot is effectively the bead which holds the two cables together. Alternatively, a single length of cable can be doubled over, passed through the aperture **66**, and knotted. In either case, the knotting **70** is provided to prevent the cable **558** from being pulled back through the aperture **66**. An adhesive may be applied to the knotting **70** to prevent unraveling, if desired. As the capstan **456** is being mounted on the actuator shaft **64**, the aperture **66** is aligned with the shaft flat **68**, generally as depicted, to positively capture the knotted portion **70** without severing the cable **558**. Thereafter, the individual free ends of the cable may be wrapped in opposite directions around the capstan **456**, as depicted in **FIG.** 3B, and routed as desired. For example, one free end may be attached to ground and the other wrapped around a clutch post before being attached to a spring which is in turn attached to ground.

[**0045**] While the capstan **456** may be a uniform cylinder, in one embodiment, the capstan **456** includes a helical channel **72** formed along an exterior surface thereof. The cable aperture **66** is aligned with a valley of the channel **72** so that both portions of the cable **558** exiting the aperture **66** can be smoothly wrapped around the capstan **456**. The opening of the aperture **66** may include a generous radius to blend the aperture **66** with the helical channel **72** without sharp edges which could cut through the cable **558** or otherwise reduce the life thereof. The helical channel **72** nests and routes the cable **558**, preventing overlapping or tangling of the cable **558** on the capstan **456**.

[**0046**] An enlarged portion of a capstan **456** with a helical channel **72** is depicted in **FIG. 5A**. The capstan **456** has a trough diameter T_D and a crest diameter C_D measured from a centerline of the capstan **456**, and a trough radius T_R. In one embodiment; T_D equals 0.175 inches, CD equals 0.189 inches, and T_R equals 0.010 inches; however, T_D, C_D, and T_R may be sized, as necessary, depending on the geometry of the cable. The helical channel **72** shown is a right hand thread with a 0.0227 pitch (i.e., **44** threads per inch); however, the capstan **456** may have a left hand thread and the thread pitch may be varied as necessary. The radial height of the channel **72** between the trough to the crest (i.e., C_D-T_D) is about equal to the radius of the cable **558**, and the trough radial contour **162** is up to about 50 percent greater than the radius of the cable **558**.

[**0047**] In one embodiment of a capstan, such as that shown in **FIG.** 5A, the helical channel **72** has a uniform radius (T_R) for nesting and routing the cable **558**. The channel **72** could be V-shaped; however, the U-shape of a channel **72** with a uniform radius is believed to support the cable better and enhance useful cable life. The centerline **158** of the cable **558** should be approximately aligned with