7 of the torsion spring 8 is reduced to zero, which is detected by the controller 33 through both the force/torque sensor 29 and the angular position sensor 59.

[0161] Vice versa, if a desired force/torque 32 applied by output shaft 11 to an external load (not shown) connected to this output shaft needs to be raised, the wave generator 4 is rotated in the appropriate direction and the reaction force/torque will raise inside the torsion spring 8 and consequently the output force/torque applied to the external load (not shown) through the output shaft 11 will also increase. Again, sensor 29 will measure the force/torque until the desire force/torque is reached and sensor 59 will measure the corresponding angular motion.

[0162] The embodiment of FIGS. 18 and 19 presents, amongst others, the following advantages:

[0163] Since a force/torque is applied to the external load (not shown) through the output shaft 11 and the transducer T2 against a force/torque produced by transducer T1, and since a force/torque applied by the external load (not shown) to the output shaft 11 is compensated for at least in part through transducer T1 to make easier compensation of this force/torque and the corresponding angular motion through transducer T2, the mechanical differential along with the transducers T1 and 72 define a dynamic relationship between force/torque and speed applied to the load at the mechanical port connected to this load.

[0164] This allows transducers T1 and 72 along with the mechanical differential to accurately and efficiently adjust the force/torque and angular speed applied to the external load through the output shaft, as well as to efficiently and accurately compensate for a force/torque and angular speed induced to the output shaft 11 by the same external load. In this manner, an interaction of a port of a robot on a load can be accurately and efficiently controlled.

[0165] The differential actuator of FIGS. 18 and 19 constitutes a high performance actuator of compact design. This actuator is particularly, but not exclusively, well suited for integration in robotic mechanisms.

[0166] Although differential coupling between an intrinsically high impedance transducer T1 and an intrinsically low impedance transducer T2 provides similar benefits as serial coupling of the transducers, differential coupling enables interesting more compact and simple design implementation possibilities in particular, but not exclusively, for rotational actuators.

[0167] In a differential actuator such as the one shown in FIGS. 18 and 19, the mechanical impedance $Z_2$ of transducer T2, which is in general very difficult to model, does not influence the mechanical impedance $Z_{eq}$ of the differential actuator. As a result, an interaction control between the differential actuator and the load can be performed solely with impedance and/or force/torque control of transducer T1.

[0168] Implementation of a force controllable differential actuator with variable and controllable impedance dynamic reaction

[0169] The embodiment shown in FIG. 20 uses a hollow shaft harmonic drive WG-FS-CS to implement a differential coupling between an unlimited angle direct drive brushless motor R1-S1 and a limited angle direct drive brushless torque motor R2-S2. An example of company that manufactures limited and unlimited angle torque motors is the American company Axsys [12]. Limited angle torque motors have only one stator winding. They do not need complex commutation electronics and they have a clean torque output without ripple. The key point to understand the advantage of using limited angle torque motors is that compared to unlimited angle brushless direct drive torque motors of the same size, limited angle torque motors can produce higher torques within a large frequency bandwidth (from stationary to high frequencies) because the winding current interact with all the rotor magnets at the same time. The mechanical volume occupied by limited angle or unlimited angle torque motor has the geometry of a tore. In the design of FIG. 20, the rest of the differential actuator mechanism advantageously fits within the free space at the center of the tore allowing the construction of a compact unlimited angle high performance actuator combining all the advantages of the limited angle torque motor (i.e. very high torque output within a large frequency bandwidth, very low intrinsic mechanical impedance, direct force controllability) and the principal advantage of the central unlimited angle direct drive motor (unlimited angle rotation capability).

[0170] Controlling the output torque/torque can be done either by using a force transducer and a feedback controller or by controlling the winding current using a feed forward model based on the position state feedback of the rotor R2. One advantage of this second control scheme is that the transducer winding and the current sensor are collocated allowing very fast analog control of the torque. An appropriate speed control of the unlimited angle motor ensures that the limited angle torque motor stays inside its functional range of angle displacement.

[0171] The above described illustrative embodiments of the present invention are particularly, but not exclusively, suitable for compact implementation designs of high performance actuators which are especially adapted for integration in robotic mechanisms. Many robotic tasks that require a precise interaction control between a robot and the robot's environment can benefit from these designs. The application fields are numerous, including, amongst others:

[0172] Actuation of active suspension mechanisms for robotic vehicles (from rovers to legged robots);

[0173] Actuation of robotic arms for fast assembly tasks;

[0174] Actuation of safe robotic arms working in human environments;

[0175] Actuation of robots for surgery;

[0176] Actuation of limbs for humanoids robots;

[0177] Actuation of hyper motorized robotic mechanisms;

[0178] Actuation of human exoskeleton for gesture assistance (arm, hand);

[0179] Actuation of human exoskeleton for physiotherapy;

[0180] Actuation of physiotherapy robot;

[0181] Actuation of massage robot;

[0182] Actuation of a robot for polishing;