Reality Systems," in abstracts of the International Conference On ER Fluids, MR Suspensions and their Applications, Jul. 22-25, 1997 Yonezawa, Japan, pg. 51-52. An ER actuator comprises a device that contains an ER fluid, which is a substance that changes its shear strength with application of an electric field. The ER fluid can then be used as a clutch or a brake to increase resistance between two members.

[0010] The use of such an ER actuator is severely disadvantageous, however, for use in typical haptic interface systems. One major issue is that an ER actuator presents a major safety problem because of the high electric voltage required to produce the electric field necessary to generate a desired change in shear strength in the ER fluid. For a haptic interface system, a typical ER fluid actuator may require voltages in the range of about 1000 to 5000 volts. Conversely, the motors used in the typical systems described above require in the range of about 500 milliamps (mA) to 1.0 A of current. Thus, the voltage required to operate an ER actuator is very high, making an ER actuator undesirable, and possibly unsafe, for a consumer device subject to a great amount of wear and tear.

[0011] Additionally, an ER actuator detrimentally requires expensive seals to hold the ER fluid within cavities within the actuator. Seals frequently wear, causing reliability problems for ER actuators and concerns about ER fluid leaks. Further, the use of seals typically requires machined parts having tight tolerances, additionally increasing the cost of the ER actuator. Also, ER actuators require expensive bearings to insure the relative positioning of the tight-tolerance parts.

[0012] Similarly, precise machining is required for the internal rotating components of an ER actuator, further increasing the cost of the actuator. Because an ER device requires a relatively large amount of surface area between the ER fluid and the two members that the ER fluid contacts, tight tolerance machining is needed between the multiple, adjacent surfaces of the members. Thus, a relatively large amount of surface area may be required to generate sufficient torque to provide the levels of force feedback required by typical haptic interface systems.

[0013] Finally, typical ER actuators that provide appropriate force may be too large to be integrated into a commercial haptic interface system. The device utilized to provide force feedback in a typical haptic interface system must be small and lightweight in order to be practically integrated into the system. An ER actuator meeting these requirements is very costly to produce, besides having the above-stated deficiencies. Thus, utilization of an ER actuator in a typical haptic interface system is not desirable.

[0014] Therefore, it is desirable to provide a haptic interface system that is more simple, cost-effective, reliable and better performing than the above-stated prior art.

SUMMARY OF THE INVENTION

[0015] According to a preferred embodiment of the present invention, a haptic interface system of the present invention comprises a magnetically-controllable device that advantageously provides a variable resistance force that opposes movement of a haptic interface device to provide force feedback sensations. The haptic interface device is in operative contact with the operator of a vehicle, machine or computer system. The magnetically-controllable device beneficially comprises a magnetically-controllable medium between a first and second member, where the second member is in communication with the haptic interface device. For purposes of this description, the magnetically controllable medium shall include any magnetically controllable material such as a magnetorheological fluid or powder. The magnetically-controllable medium provides the variable resistance force, in proportion to the strength of an applied magnetic field, that opposes relative movement between the first and second members. The haptic interface system of the present invention may be used to control vehicle steering, throttling, clutching and braking; computer simulations; machinery motion and functionality. Examples of vehicles and machinery that might include the haptic interface system of the present invention comprise industrial vehicles and watercraft, overhead cranes, trucks, automobiles, and robots. The haptic interface device may comprise, but shall not be limited to a steering wheel, crank, foot pedal, knob, mouse, joystick and lever.

[0016] Furthermore, the controller may send signals to the vehicle, machine or computer simulation **30** in response to information obtained by sensor **32** and other inputs **30** for purposes of controlling the operation of the vehicle, machine or computer simulation. See **FIGS. 1A and 1B**. Once the operator inputs and other inputs are processed by micrprocessor **54**, a force feedback signal is sent to the magnetically controllable device **24** which in turn controls the haptic interface **26** such as a joystick, steering wheel, mouse or the like to reflect the control of the vehicle, machine or computer simulation.

[0017] The system additionally comprises a controller, such as a computer system, adapted to run an interactive program and a sensor that detects the position of the haptic interface device and provides a corresponding variable input signal to the controller.

[0018] The controller processes the interactive program, and the variable input signal from the sensor, and provides a variable output signal corresponding to a semi-active, variable resistance force that provides the operator with tactile sensations as computed by the the interactive program. The variable output signal energizes a magnetic field generating device, disposed adjacent to the first and second members, to produce a magnetic field having a strength proportional to the variable resistance force. The magnetic field is applied across the magnetically-controllable medium, which is disposed in a working space between the first and second members. The applied magnetic field changes the resistance force of the magnetically-controllable medium associated with relative movement, such as linear, rotational or curvilinear motion, between the first and second members in communication with the haptic interface device. As such, the variable output signal from the controller controls the strength of the applied magnetic field, and hence the variable resistance force of the magnetically-controllable medium. The resistance force provided by energizing the magnetically-controllable medium controls the ease of movement of the haptic interface device among a plurality of positions. Thus, the present haptic interface system provides an operator of a vehicle, machine, or computer simulation, force feedback sensations through the magnetically-controllable device that opposes the movement of the haptic interface device.