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**Salcudean et al.**

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(54) **CONTROLLER**

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JP H4-92691 3/1992  
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JP H6-210065 8/1994  
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**OTHER PUBLICATIONS**

Computing with Feeling—Atkinson et al *Computers & Graphics* vol. II Jan. 1977 pp. 97–103.  
Artificial Reality with Force Feedback; Development of Desktop Virtual Space with Compact Master Manipulator—Iwata—*Siggraph* Dallas Aug. 6–10, 1990.  
Creating an Illusion of Feel: Control Issues & Force Display—Ouh—Young et al Sep. 16, 1989.

**Related U.S. Patent Documents**

Reissue of:

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**G09G 5/00** (2006.01)

(57) **ABSTRACT**

(52) **U.S. Cl.** ..... **345/184**; 345/157; 715/701

(58) **Field of Classification Search** ..... 345/157,  
345/184, 701, 156, 161, 163, 158, 166, 702;  
715/701, 702; 463/37, 38, 30; 273/148 B,  
273/148 R

A mouse controller includes a platform mounted on a base for a range of movement in a plane relative to the base of at least ½ inch (12.5 mm) in each of two different directions (preferably mutually perpendicular directions). A pair of flat, elongated coils (Lorentz voice coils) are mounted on the platform with their longitudinal axes extending one in each of the two directions. Each of the coils cooperates with at least one magnet fixed to the base. The sizes of the magnets and of the coils and the relative positions of the cooperating coils and magnets are made or their operation controlled so that, in the range of relative movement between the platform and base, preselected forces between the coils and the magnets may be generated by a control computer. Preferably the projected area of the field from each of the permanent magnets onto the coil with which it cooperates will be substantially constant regardless of the position of the platform within the range so that the same current is required to generate the same force anywhere within the range. The control computer is programmed to activate the coils to controllably apply forces to the platform and thereby to facilitate movement of the platform and feed back tactile sensations to the operator.

See application file for complete search history.

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

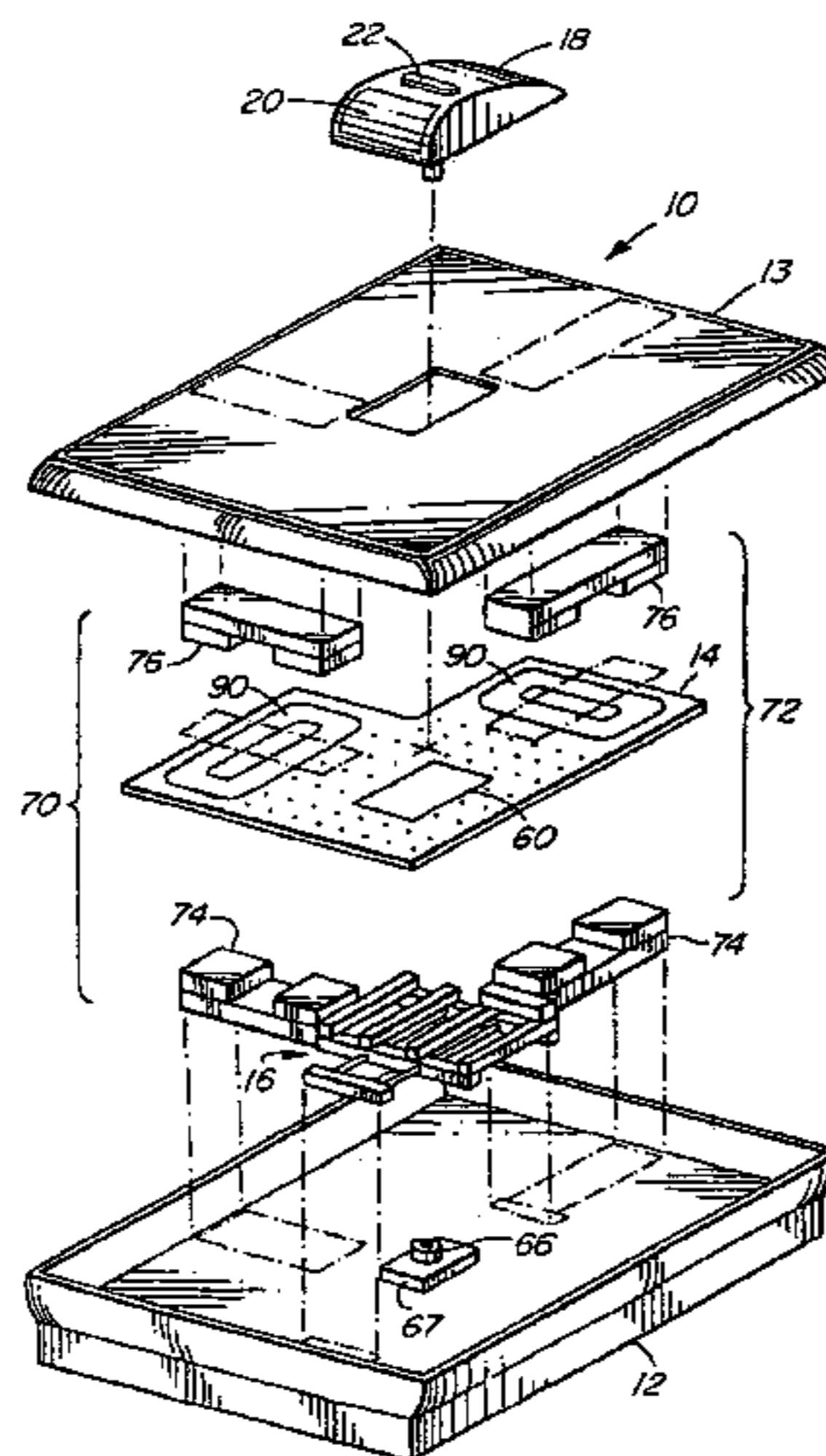
3,157,853 A 11/1964 Hirsch  
3,220,121 A 11/1965 Cutler  
3,497,668 A 2/1970 Hirsch

(Continued)

**FOREIGN PATENT DOCUMENTS**

EP 0 085 518 A1 8/1983  
EP 0 265 011 A1 4/1988  
EP 0349086 1/1990  
EP 0 607 580 A1 7/1994  
JP S62-194389 12/1987

**54 Claims, 7 Drawing Sheets**



# US RE40,341 E

## U.S. PATENT DOCUMENTS

3,517,446 A	6/1970	Corlyon et al.	5,146,566 A *	9/1992	Hollis, Jr. et al. ....	710/73
3,623,064 A	11/1971	Kagan	5,184,319 A	2/1993	Kramer .....	364/806
3,863,098 A	1/1975	Mehr .....	5,185,561 A	2/1993	Good et al. ....	318/432
3,902,687 A	9/1975	Hightower	5,186,629 A	2/1993	Rohen .....	434/114
3,903,614 A	9/1975	Diamond et al.	5,193,963 A	3/1993	McAffee et al. ....	414/5
3,919,691 A	11/1975	Noll	5,197,003 A	3/1993	Moncrief et al. ....	364/410
4,148,014 A	4/1979	Burson .....	5,203,563 A	4/1993	Loper, III .....	273/148 B
4,160,508 A	7/1979	Salsbury	5,209,661 A	5/1993	Hildreth et al. ....	434/45
4,199,875 A	4/1980	Barbarasch .....	5,220,260 A	6/1993	Schuler .....	318/561
4,236,325 A	12/1980	Hall et al.	5,223,776 A	6/1993	Radke et al. ....	318/568.1
4,241,519 A	12/1980	Gilson et al. ....	5,228,356 A	7/1993	Chuang .....	74/471 XY
4,384,338 A	5/1983	Bennett .....	5,235,868 A	8/1993	Culver .....	74/471 XY
4,398,889 A	8/1983	Lam et al. ....	5,237,327 A *	8/1993	Saitoh et al. ....	341/176
4,414,984 A	11/1983	Zarudiansky .....	5,264,768 A	11/1993	Gregory et al. ....	318/561
4,477,043 A	10/1984	Repperger .....	5,275,565 A	1/1994	Moncrief .....	434/29
4,513,235 A	4/1985	Acklam et al.	5,286,203 A	2/1994	Fuller et al. ....	434/45
4,538,035 A	8/1985	Pool .....	5,296,846 A	3/1994	Ledley .....	345/161
4,546,347 A	10/1985	Kirsch	5,296,871 A	3/1994	Paley .....	345/163
4,560,983 A	12/1985	Williams .....	5,298,890 A	3/1994	Kanamaru et al. ....	345/157
4,581,491 A	4/1986	Boothroyd	5,354,162 A	10/1994	Burdea et al. ....	414/5
4,599,070 A	7/1986	Hladky et al.	5,366,376 A	11/1994	Copperman et al. ....	434/69
4,603,284 A	7/1986	Perzley .....	5,368,484 A	11/1994	Copperman et al. ....	434/69
4,604,016 A	8/1986	Joyce .....	5,381,080 A	1/1995	Schnell et al. ....	318/566
4,632,341 A	12/1986	Repperger et al. ....	5,388,992 A	2/1995	Franklin et al. ....	434/114
4,692,756 A	9/1987	Clark .....	5,389,865 A	2/1995	Jacobus et al. ....	318/568.11
4,706,294 A	11/1987	Ouchida .....	5,414,337 A	5/1995	Schuler .....	318/561
4,708,656 A	11/1987	De Vries et al.	5,435,729 A	7/1995	Hildreth et al. ....	434/365
4,712,101 A	12/1987	Culver .....	5,459,382 A	10/1995	Jacobus et al. ....	318/568.11
4,713,007 A	12/1987	Alban	5,471,571 A	11/1995	Smith et al. ....	395/137
4,734,685 A	3/1988	Watanabe .....	5,559,412 A	9/1996	Schuler .....	318/561
4,767,923 A *	8/1988	Yuasa .....	5,559,432 A	9/1996	Logue .....	324/207.17
4,782,327 A	11/1988	Kley et al. ....	5,576,727 A	11/1996	Rosenberg et al. ....	345/179
4,794,384 A	12/1988	Jackson	5,589,828 A *	12/1996	Armstrong .....	341/20
4,794,392 A	12/1988	Selinko	5,629,594 A	5/1997	Jacobus et al. ....	318/568.11
4,795,296 A	1/1989	Jau .....	5,634,794 A	6/1997	Hildreth et al. ....	434/37
4,799,055 A	1/1989	Nestler et al.	5,691,898 A	11/1997	Rosenberg et al. ....	364/190
4,800,721 A	1/1989	Cemenska et al. ....	5,696,537 A	12/1997	Solhjell .....	345/164
4,823,634 A	4/1989	Culver .....	5,701,140 A	12/1997	Rosenberg et al. ....	345/156
4,861,269 A	8/1989	Meenen, Jr. ....	5,721,566 A	2/1998	Rosenberg et al. ....	345/161
4,868,549 A *	9/1989	Affinito et al. ....	5,734,373 A	3/1998	Rosenberg et al. ....	345/161
4,878,183 A	10/1989	Ewart .....	5,739,811 A	4/1998	Rosenberg et al. ....	345/161
4,879,556 A	11/1989	Duimel .....	5,757,358 A	5/1998	Osga .....	345/146
4,891,764 A	1/1990	McIntosh	5,767,839 A	6/1998	Rosenberg .....	345/161
4,896,554 A	1/1990	Culver .....	5,781,172 A	7/1998	Engel et al. ....	345/164
4,925,312 A	5/1990	Onaga et al. ....	5,805,140 A	9/1998	Rosenberg et al. ....	345/161
4,930,770 A	6/1990	Baker	5,831,408 A	11/1998	Jacobus et al. ....	318/568.11
4,934,694 A	6/1990	McIntosh	5,844,392 A	12/1998	Peurach et al. ....	318/568.17
4,935,728 A	6/1990	Kley .....	5,880,714 A	3/1999	Rosenberg et al. ....	345/156
4,949,119 A	8/1990	Moncrief et al. ....	5,889,670 A	3/1999	Schuler et al. ....	364/186
4,961,038 A	10/1990	MacMinn .....	5,889,672 A	3/1999	Schuler et al. ....	364/188
4,983,901 A	1/1991	Lehmer .....	5,959,613 A	9/1999	Rosenberg et al. ....	345/161
5,007,300 A	4/1991	Siva .....	5,999,168 A	12/1999	Rosenberg et al. ....	345/161
5,019,761 A	5/1991	Kraft	6,028,593 A	2/2000	Rosenberg et al. ....	345/156
5,022,407 A	6/1991	Horch et al.	6,037,927 A	3/2000	Rosenberg .....	345/156
5,035,242 A	7/1991	Franklin et al.	6,046,727 A	4/2000	Rosenberg et al. ....	345/156
5,038,089 A	8/1991	Szakaly	6,050,718 A	4/2000	Schena et al. ....	364/190
5,044,956 A	9/1991	Behensky et al. ....	6,057,828 A	5/2000	Rosenberg et al. ....	345/156
5,065,145 A *	11/1991	Purcell .....	6,100,874 A	8/2000	Schena et al. ....	345/157
5,076,517 A	12/1991	Ferranti et al. ....	6,104,158 A	8/2000	Jacobus et al. ....	318/568.11
5,078,152 A	1/1992	Bond et al.	6,166,723 A	12/2000	Schena et al. ....	345/184
5,086,197 A *	2/1992	Liou .....				
5,086,296 A	2/1992	Clark .....				
5,095,303 A	3/1992	Clark et al. ....				
5,103,404 A	4/1992	McIntosh .....				
5,107,080 A	4/1992	Rosen .....				
5,107,262 A *	4/1992	Cadoz et al. ....				
5,113,179 A	5/1992	Scott-Jackson .....				
5,116,180 A	5/1992	Fung et al. ....				
5,125,077 A *	6/1992	Hall .....				
5,142,931 A	9/1992	Menahem .....				

## OTHER PUBLICATIONS

NASA Technology Transfer Division—Force Feedback Control May 1990.

“Sawyer—Principle” —GS Xynetics—Design News Nov. 7, 1988.

Fischer, et al., “Specification and Design of Input Devices for Teleoperation,” CH2876-1/90/0000, pp. 540-545, IEEE.

- Kotoku, Tetsuo, "A Predictive Display with Force Feedback and its Application to Remote Manipulation System with Transmission Time Delay," Proc. of the IEEE/RSJ Int'l Conf. On Intelligent Robots and Systems, Jul. 1992, pp. 239-246.
- Jacobsen, et al., "High Performance, High Dexterity, Force Reflective Teleoperator II," ANS Topical Mfg. On Robotics and Remote Systems, Feb. 1991, pp. 1-15.
- Kotoku, et al., "Environment Modeling for the Interactive Display (EMID) Used in Telerobotic Systems," IEEE/RSJ Int'l Workshop on Intelligent Robots and Systems, Nov. 1991, pp. 999-1004.
- Howe, et al., "Task Performance with a Dextrous Teleoperated Hand System," Proc. of SPIE, vol. 1883, Boston, Nov. 1992, pp. 1-9.
- Adelstein, et al., "A High Performance Two Degree-of-Freedom Kinesthetic Interface," MIT, 1992, pp. 108-112.
- Ouh-young, et al., "Using A Manipulator For Force Display In Molecular Docking," CH2555-1/88/0000, IEEE, pp. 1824-1829.
- Winey III, Calvin McCoy, "Computer Simulated Visual and Tactile Feedback As An Aid to Manipulator and Vehicle Control," Dept. of Mech. Eng., MIT, May 1981, pp. 1-79.
- Adelstein, et al., "Design and Implementation of a Force Reflecting Manipulandum for Manual Control Research," NASA-Ames Research Center, Dept. of Mech. Eng., MIT, 1992, pp. 1-26.
- Russo, Massimo Andrea, "The Design and Implementation of a Three Degree-of-Freedom Force Output Joystick," Dept. of Mech. Eng., May 1990, pp. 1-33.
- Bejczy, et al., "The Phantom Robot: Predictive Displays for Teleoperation with Time Delay," Jet Propulsion Lab., CH2876-1/90/0000, IEEE, pp. 546-550.
- Ouh-young, Ming, "Force Display in Molecular Docking," Dept. of Computer Science, Univ. of North Carolina, 1990, pp. i-viii, 1-12, 66-85.
- Hannaford, et al., "Performance Evaluation of a Six-Axis Generalized Force-Reflecting Teleoperator," IEEE Trans. On Systems, Man and Cybernetics, vol. 21, No. 3, May/Jun. 1991, pp. 620-623, 631-633.
- Batter, et al., "GROPE-1: A Computer Display to the Sense of Feel," Proc. IFIP Congress 1971, pp. 759-763.
- Kilpatrick, Paul Jerome, "The Use of a Kinesthetic Supplement in an Interactive Graphics System," Dept. of Computer Science, Univ. of North Carolina, 1976, pp. 1-175.
- Ouh-young, et al., "Creating an Illusion of Feel: Control Issues in Force Display," Dept. of Computer Science, Univ. of North Carolina, Sep. 1989, pp. 1-14.
- Iwata, H., "Artificial Reality with Force-Feedback: Development of Desktop Virtual Space with Compact Master Manipulator," 1990, Computer Graphics, vol. 24, pp. 165-170.
- Wiker, S. et al., "Development of Tactile Mice for Blind Access to Computers: Importance of Stimulation Locus, Object Size, and Vibrotactile Display Resolution," Proc. of Human Factors Soc., 1991, pp. 708-712.
- Atkinson et al., "Computing with Feeling, Computing & Graphics," vol. 2, 1977, pp. 97-103.
- Millman et al., "Design of a Four Degree-of-Freedom Force-Reflecting Manipulandum with a Specified Force/Torque Workspace," 1991, IEEE CH2969-4, pp. 1488-1492.
- Brooks Jr., et al., "Project GROPE-Haptic Displays for Scientific Visualization," 1990, Computer Graphics, vol. 24, pp. 177-185.
- Minsky et al., "Feeling & Seeing: Issues in Force Display," 1990, ACM 089791-351-5, pp. 235-270.
- Bostrom, M. et al., "Design of An Interactive Lumbar Puncture Simulator with Tactile Feedback," IEEE 0-7803-1363-1, 1993, pp. 280-286.
- Iwata, H., "Pen Based Haptic Virtual Environment," IEEE 0-7803-1363-1, 1993, pp. 287-292.
- "Foot-operated Mouse," IBM Technical Disclosure Bulletin, vol. 28, No. 11, 1986.
- Rutherford, M. "Third Generation Digital Flight Controls," CAE Electronics, Ltd., The Royal Aeronautical Society, 1984 Spring Convention Future Applications and Prospects for Flight Simulation, May 9-10, 1984, paper No. 15.
- De Vries, L. and Wierda, G. J., "Performance Considerations, Design Criteria and Realization of a Digital Control Loading System," International Air Transport Association, Seventh Flight Simulator Technical Sub-Committee Meeting, Agenda Item 10, Montreal, Sep. 17-20, 1984.
- Baradat, Jean and Lacroix, Michel, "Advanced Features in Control Loading and Motion Systems for Simulators," National Security Industrial Association 1<sup>st</sup> Interservice/Industry Training Equipment Conference Proceedings, Nov. 27-29, 1981.
- Norlin, Ken A., "Flight Simulation Software at NASA Dryden Flight Research Center," American Institute of Aeronautics and Astronautics Flight Simulation Technologies Conference, Baltimore, MD, Aug. 7-10, 1995.
- Corrao, Joseph M., "Control Loading," American Institute of Aeronautics and Astronautics Flight Simulation Update 1987, Jan. 12-16, 1987.
- Corrao, J.M., "Control Loading," American Institute of Aeronautics and Astronautics Flight Simulation Update 1988, Jan. 11-15, 1988.
- Rinaldi, P., "Digital Control Loading—A Modular Approach," International Air Transport Association 6<sup>th</sup> Meeting of the Flight Simulator Technical Sub-Committee, Montreal, Jun. 1-4, 1982.
- Hildreth, Bruce L., Eyer mann, Roger E. and Trankle, Thomas Dr., "DC Servo-Motors for High Performance High Reliability Control Loading in Flight Simulators," American Defense Preparedness Association 12<sup>th</sup> Interservice/Industry Training System Conference, Nov. 6-8, 1990.
- Baigrie, Stephen A., Reflectone Inc., "Electric Control Loading—A Low Cost, High Performance Alternative," American Defense Preparedness Association 12<sup>th</sup> Interservice/Industry Training System Conference, Nov. 6-8, 1990.
- "Digital Control Loading", Giel et al., Summary, Paper 2, Paper 3, International Air Transport Association, Seventh Flight Simulator Technical Sub-Committee Meeting, Item No. 10, Montreal, Sep. 17-20, 1984.
- Seidensticker, Steve, "Application of Microcomputers to the Simulator 'Linkage' Problem," National Security Industrial Association 4<sup>th</sup> Interservice/Industry Training Equipment Conference Proceedings, Nov. 16-18, 1982.
- Flight Simulation, Rolfe, J.M. and Staples, K. J., eds., 1986.
- Albers, F. Gerry, "Microcomputer Base for Control Loading," Naval Training Equipment Center 11<sup>th</sup> NTEC-Industry Conference Proceedings, NAVTRAEQUIPCEN IH-306, No. 14-16, 1978.

- Baigrie, "Electric Control Loading—A Low Cost, High Performance Alternative," Proceedings, pp. 247–254, Nov. 6–8, 1990.
- Brooks et al., "Hand Controllers for Teleoperation—A State-of-the-Art Technology Survey and Evaluation," JPL Publication 85–11; NASA–CR–175890; N85–28559, pp. 1–84, Mar. 1, 1985.
- Jones et al., "A perceptual analysis of stiffness," ISSN 0014–4819 Springer International (Springer–Verlag); Experimental Brain Research, vol. 79, No. 1, pp. 150–156, 1990.
- Snow et al., "Model–X Force–Reflecting–Hand–Controller," NT Control No. MPO–17851; JPL Case No. 5348, pp. 1–4, Jun. 15, 1989.
- Ouh–Young, "Force Display in Molecular Docking," Order No. 9034744, p. 1–369, 1990.
- Tadros, Control System Design for a Three Degree of Freedom Virtual Environment Simulator Using Motor/ Brake Pair Actuators, MIT Archive © Massachusetts Institute of Technology, pp. 1–88, Feb. 1990.
- Gotow et al., "Controlled Impedance Test Apparatus for Studying Human Interpretation of Kinesthetic Feedback," WA11–11:00, pp. 332–337, Jun., 1989.
- Stanley et al., "Computer Simulation of Interacting Dynamic Mechanical Systems Using Distributed Memory Parallel Processors," DSC–Vol. 42, Advances in Robotics, pp. 55–61, ASME 1992.
- Russo, "Controlling Dissipative Magnetic Particle Brakes in Force Reflective Devices," DSC–Vol. 42, Advances in Robotics, pp. 63–70, ASME 1992.
- Patrick et al., "Design and Testing of A Non–reactive, Fingertip, Tactile Display for Interaction with Remote Environments," Cooperative Intelligent Robotics in Space, Rui J. deFigueiredo et al., Editor, Proc. SPIE vol. 1387, pp. 215–222, 1990.
- Adelstein, "A Virtual Environment System For The Study of Human Arm Tremor," Ph.D. Dissertation, Dept. of Mechanical Engineering, MIT, Jun. 1989.
- Bejczy, "Sensors, Controls, and Man–Machine Interface for Advanced Teleoperation," Science, vol. 208, No. 4450, pp. 1327–1335, 1980.
- Bejczy, "Generalization of Bilateral Force–Reflecting Control of Manipulators," Proceedings Of Fourth CISM–IF–ToMM, Sep. 8–12, 1981.
- McAfee, "Teleoperator Subsystem/Telerobot Demonstration: Force Reflecting Hand Controller Equipment Manual," JPL 1988.
- Shimoga, "Finger Force and Touch Feedback Issues in Dexterous Telemanipulation," Proceedings of Fourth Annual Conference on Intelligent Robotic Systems for Space Exploration, Rensselaer Polytechnic Institute, Sep. 30–Oct. 1, 1992.
- IBM Technical Disclosure Bulletin, "Mouse Ball–Actuating Device With Force and Tactile Feedback," vol. 32, No. 9B, Feb. 1990.
- Terry et al., "Tactile Feedback In A Computer Mouse," Proceedings of Fourteenth Annual Northeast Bioengineering Conference, University of New Hampshire, Mar. 10–11, 1988.
- Howe, "A Force–Reflecting Teleoperated Hand System for the Study of Tactile Sensing in Precision Manipulation," Proceedings of the 1992 IEEE International Conference on Robotics and Automation; Nice, France, May 1992.
- Rabinowitz et al., "Multidimensional tactile displays: Identification of vibratory intensity, frequency, and contactor area," Journal of The Acoustical Society of America, vol. 82, No. 4, Oct. 1987.
- Bejczy et al., "Kinesthetic Coupling Between Operator and Remote Manipulator," International Computer Technology Conference. The American Society of Mechanical Engineers, San Francisco, CA, Aug. 12–15, 1980.
- Bejczy et al., "A Laboratory Breadboard System For Dual–Arm Teleoperation," SOAR '89 Workshop, JSC, Houston, TX, Jul. 25–27, 1989.
- Bejczy, et al., "Universal Computer Control System (UCCS) For Space Telerobots," CH2413–3/87/0000/0318501.00 1987 IEEE, 1987.

\* cited by examiner

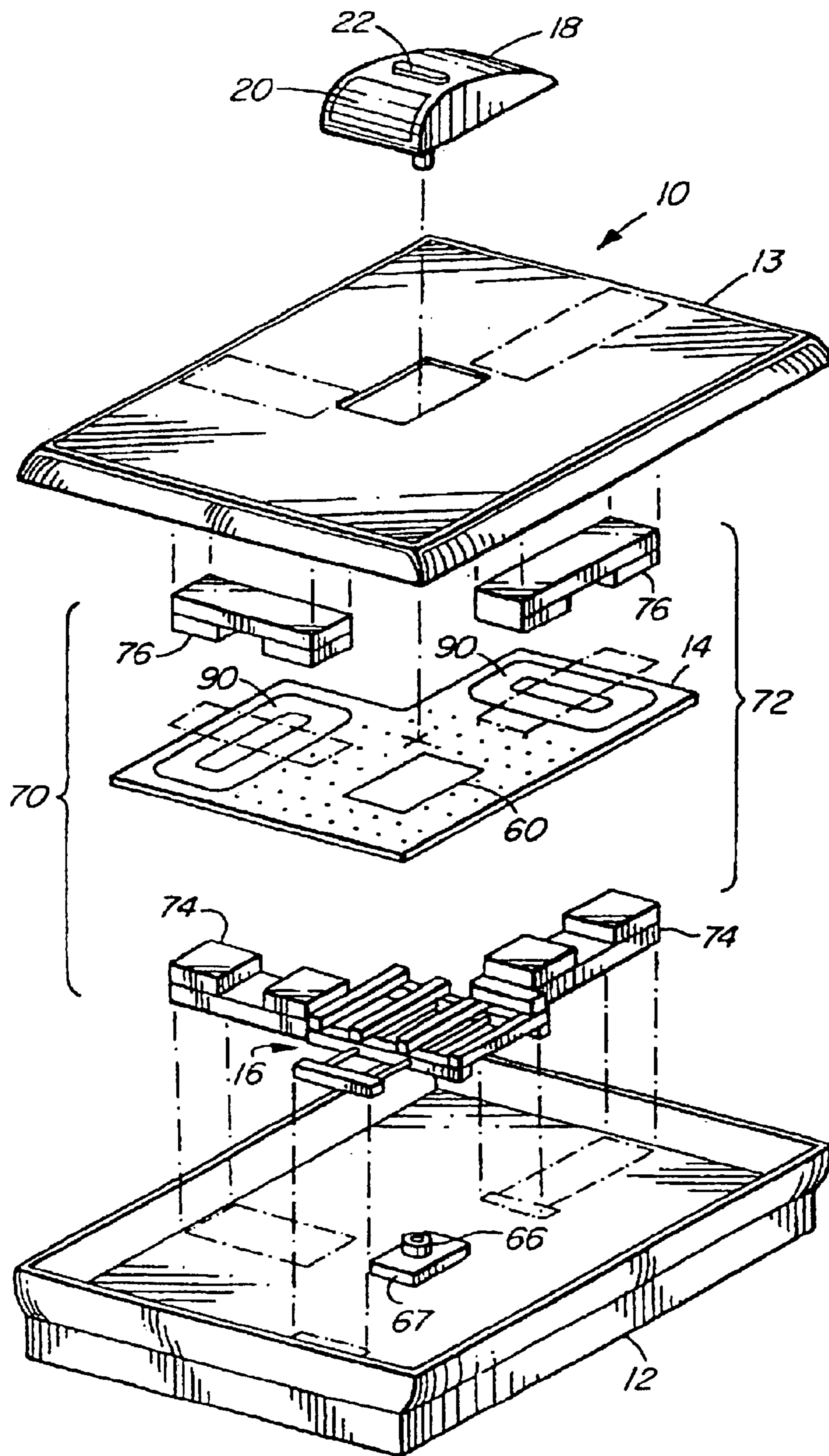


FIG. 1

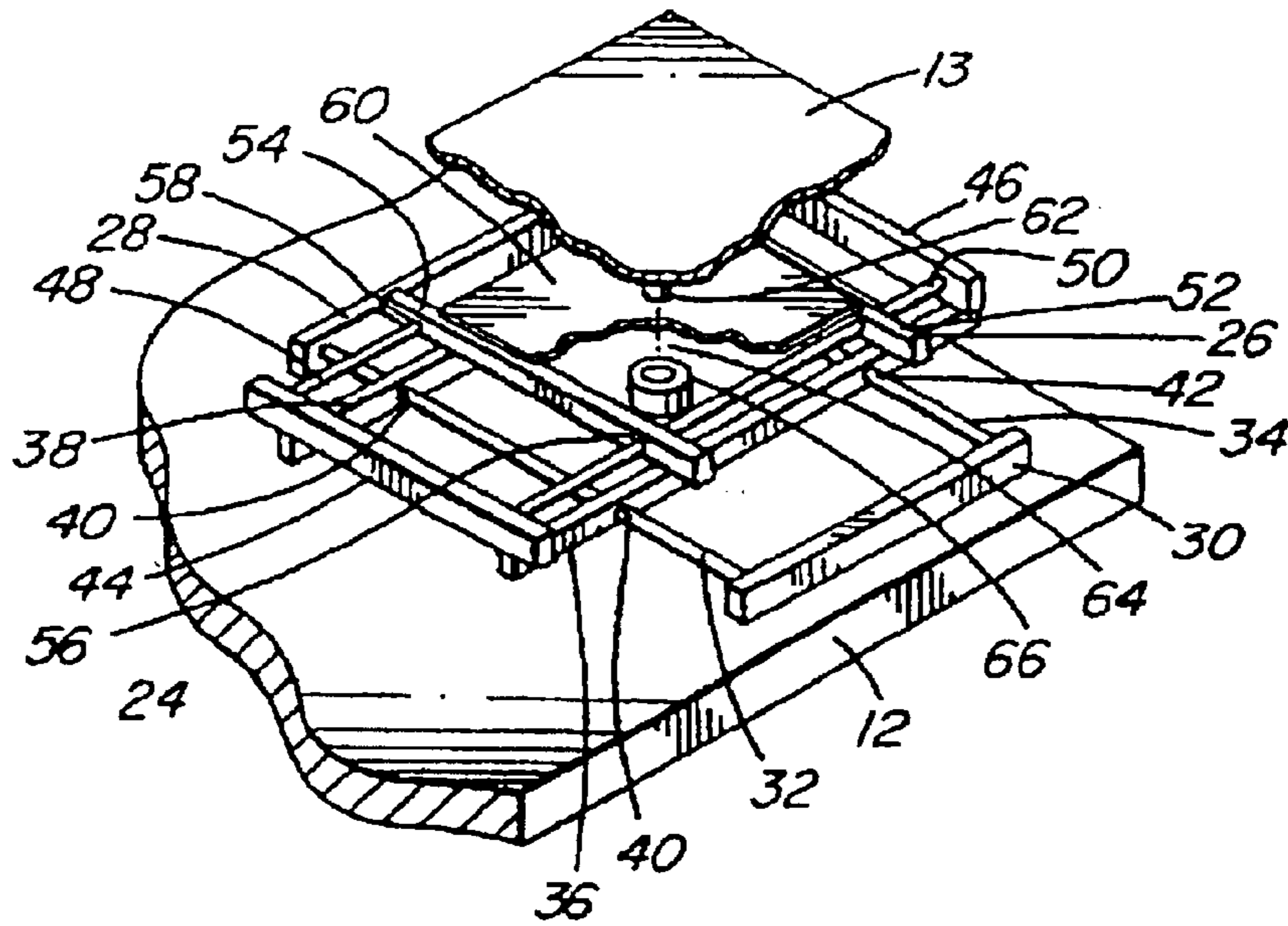


FIG. 2

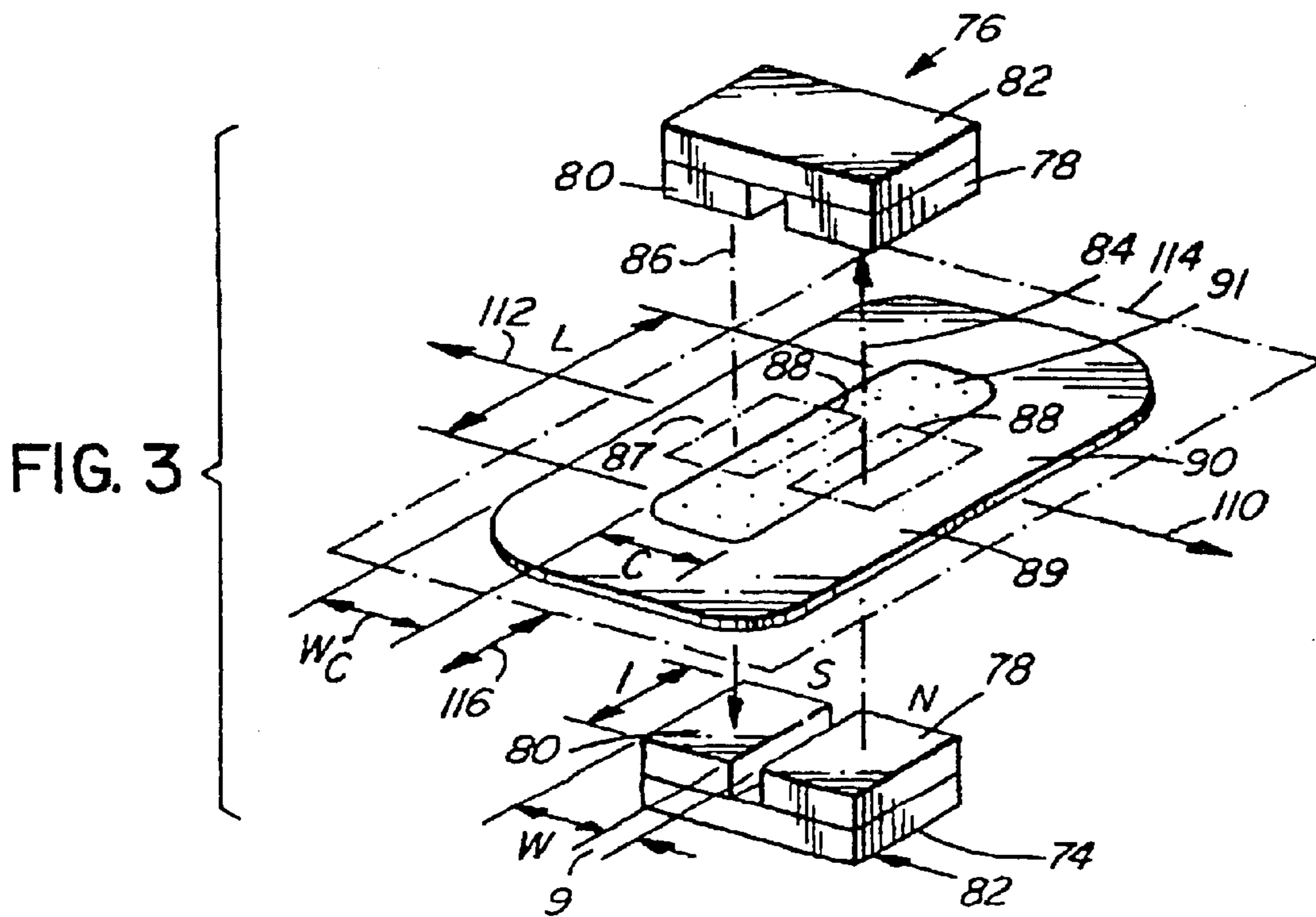


FIG. 3

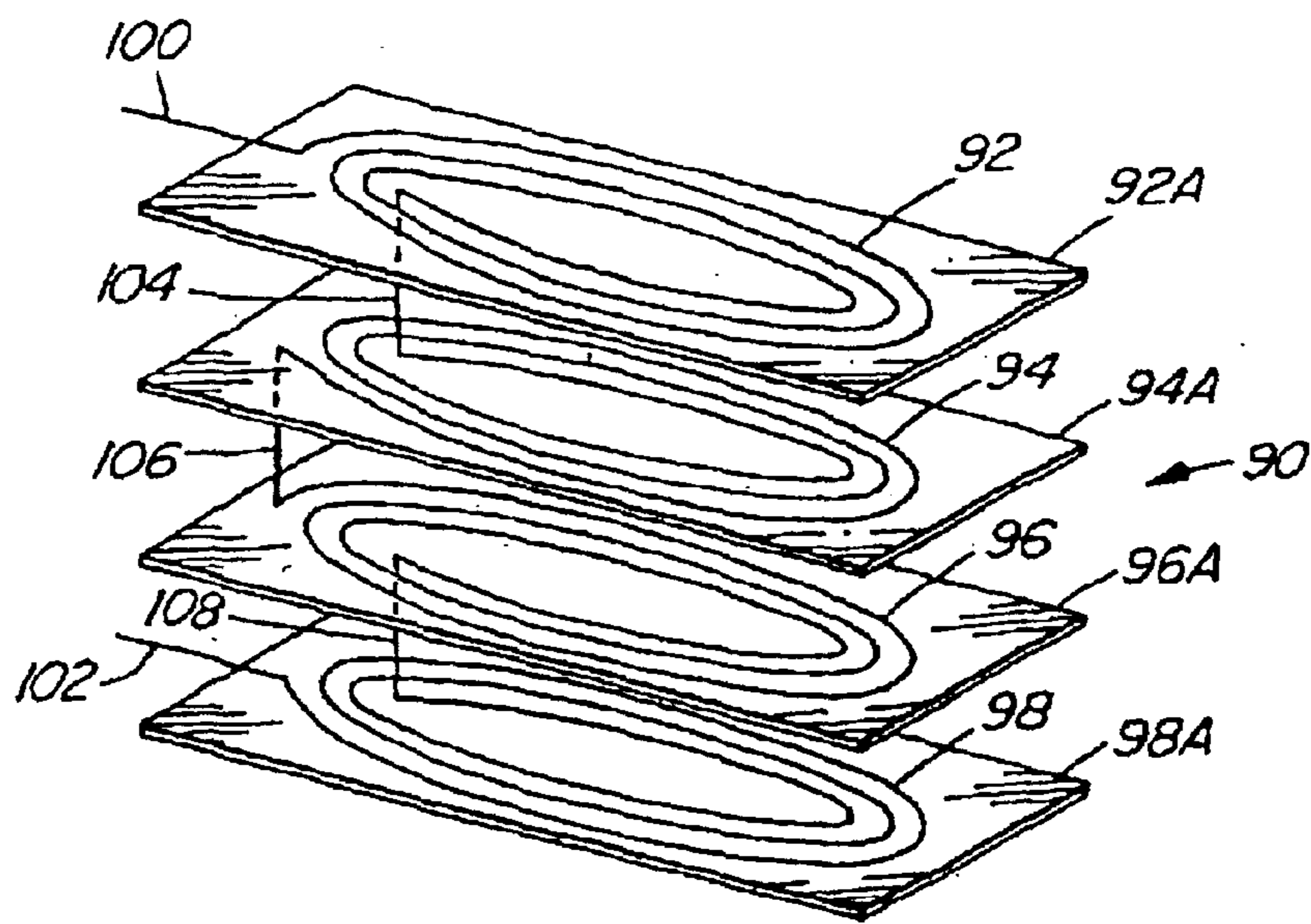


FIG. 4

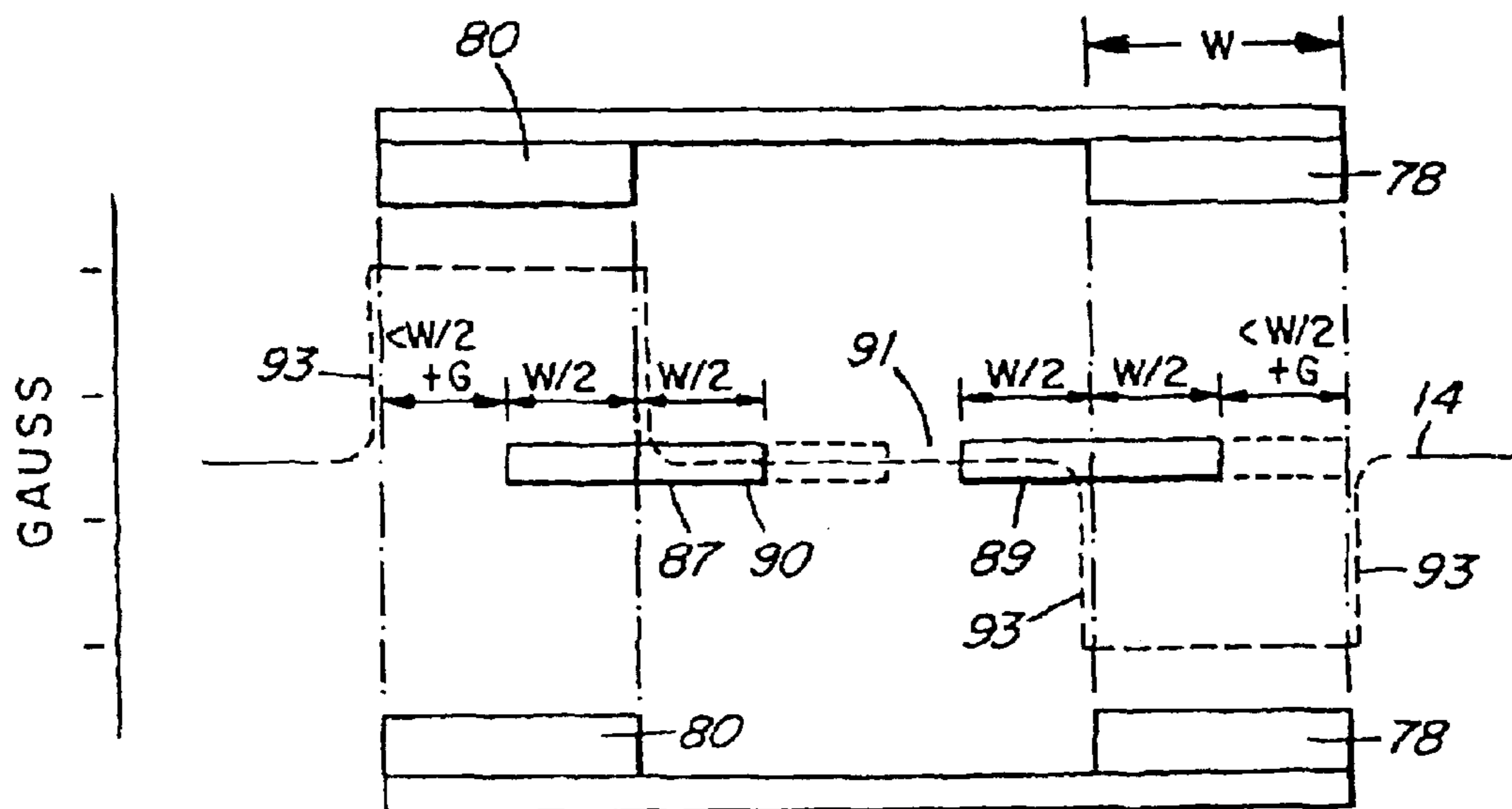


FIG. 5

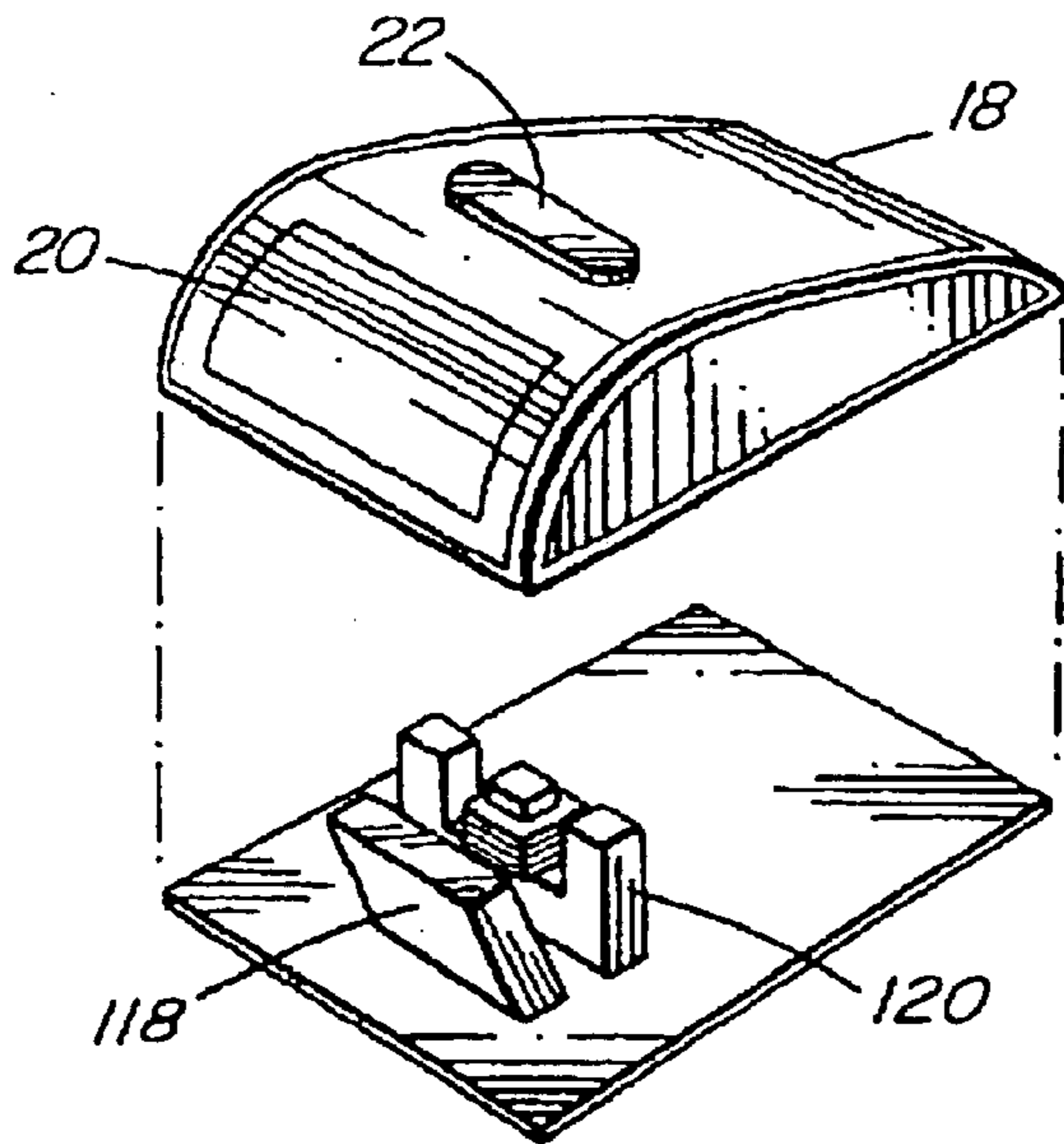


FIG. 6

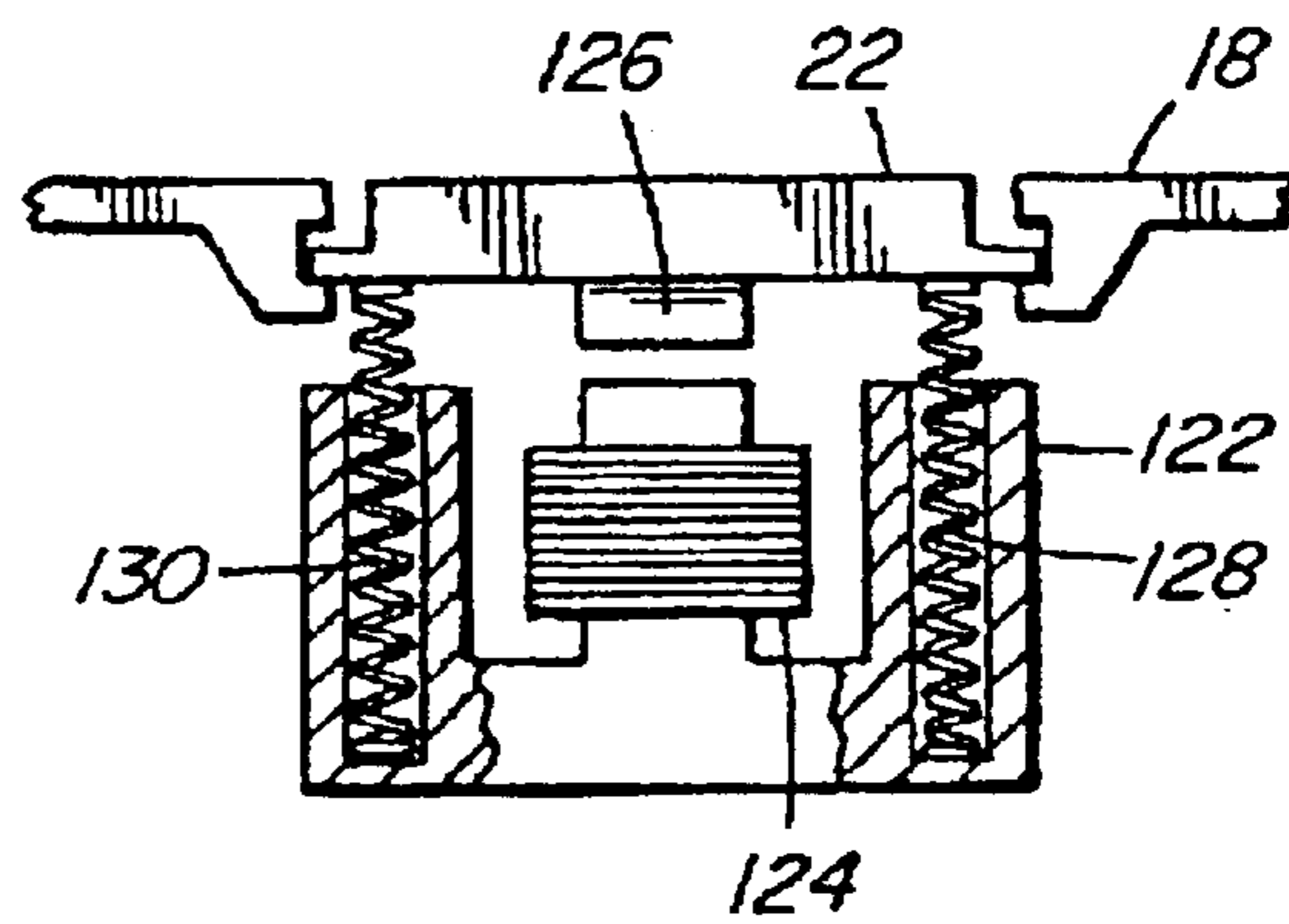


FIG. 7

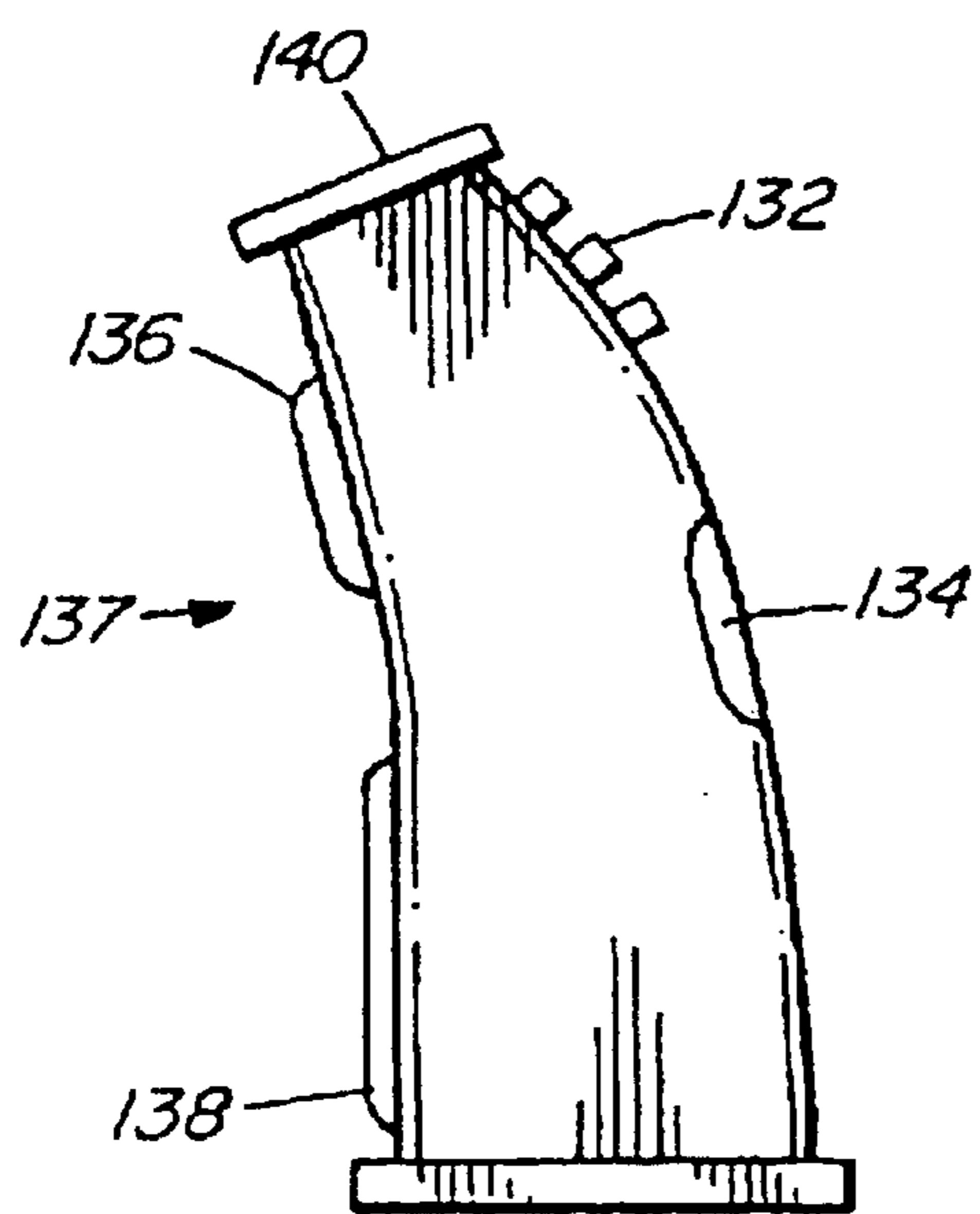


FIG. 8



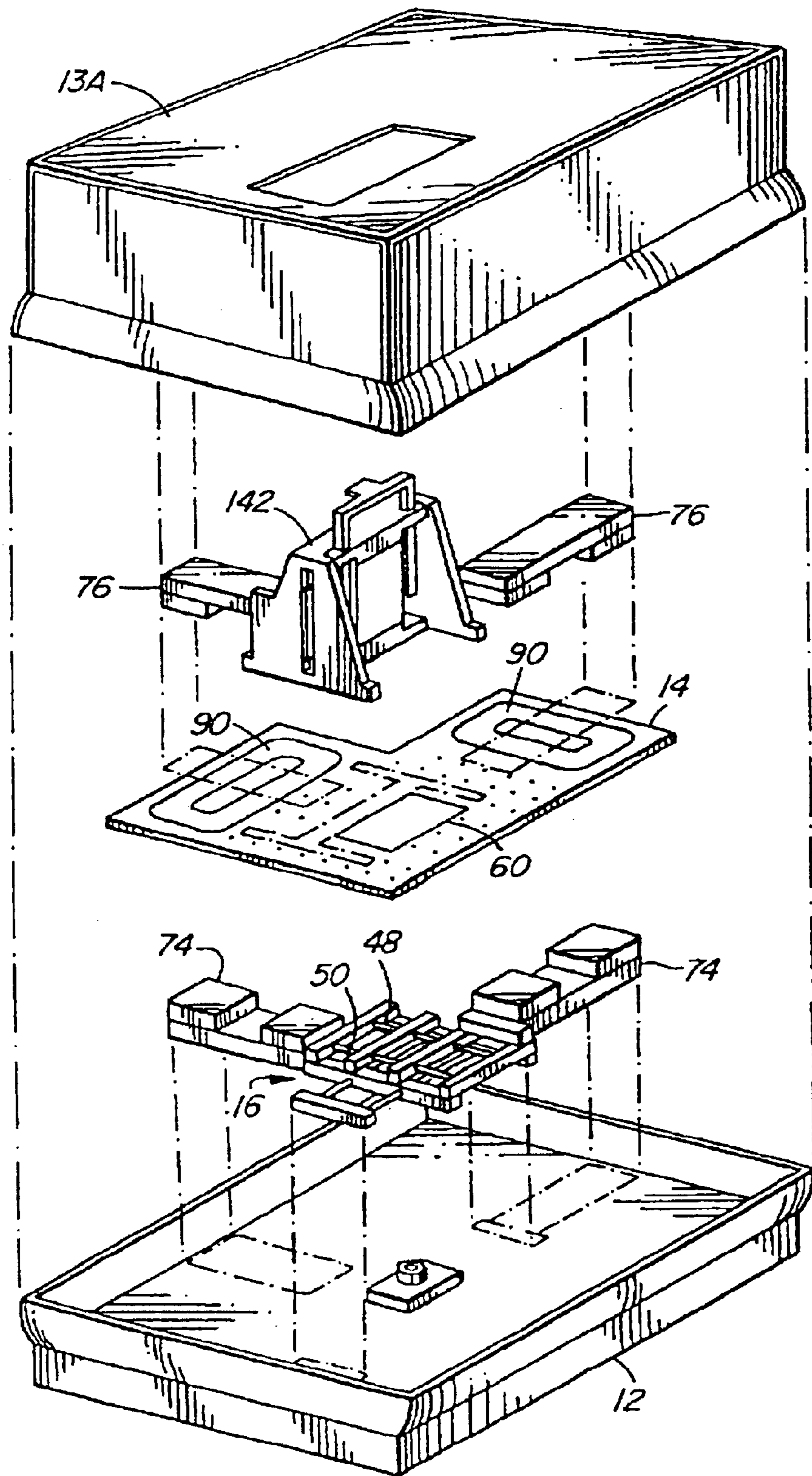


FIG. 9

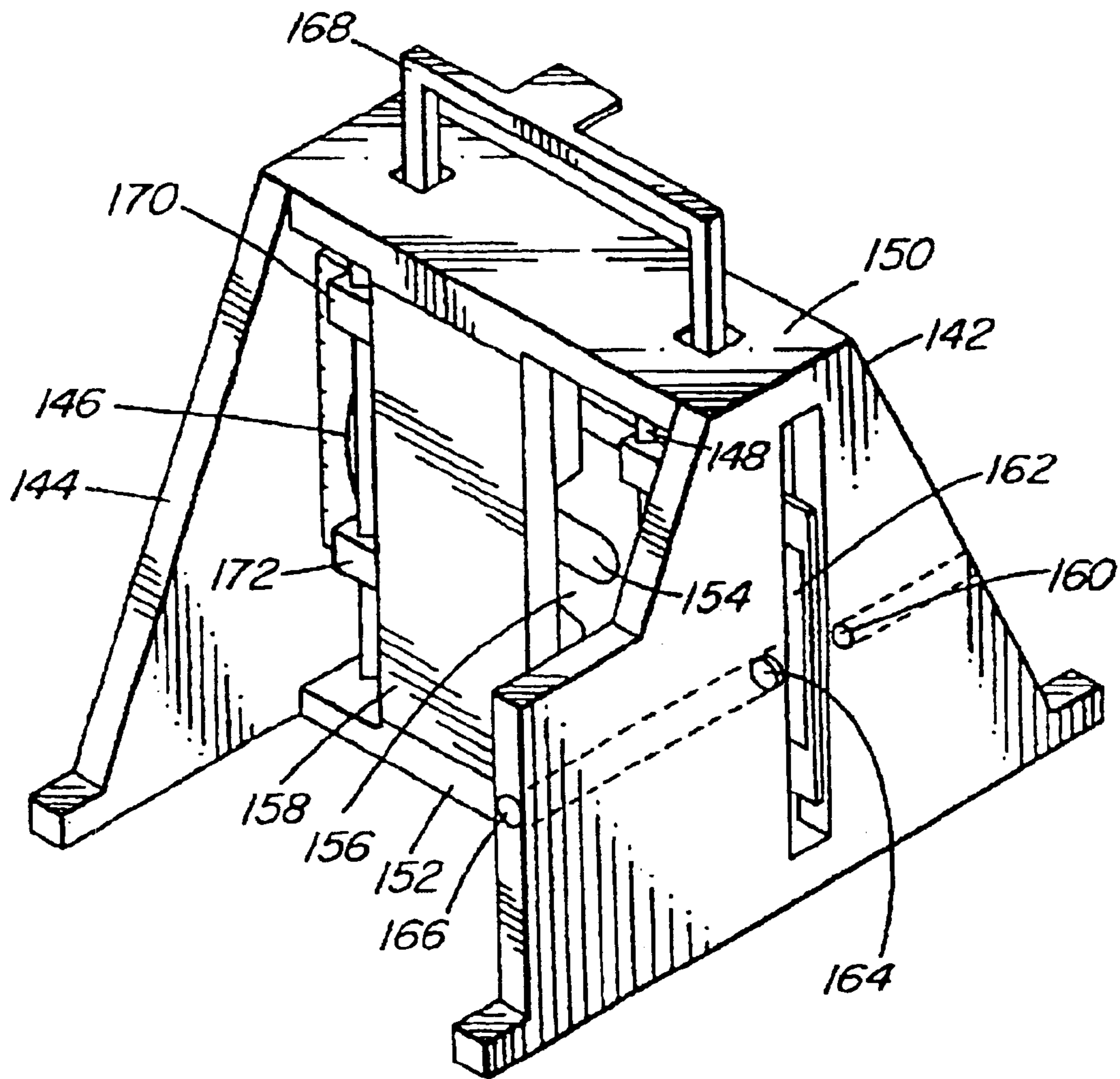


FIG. 10

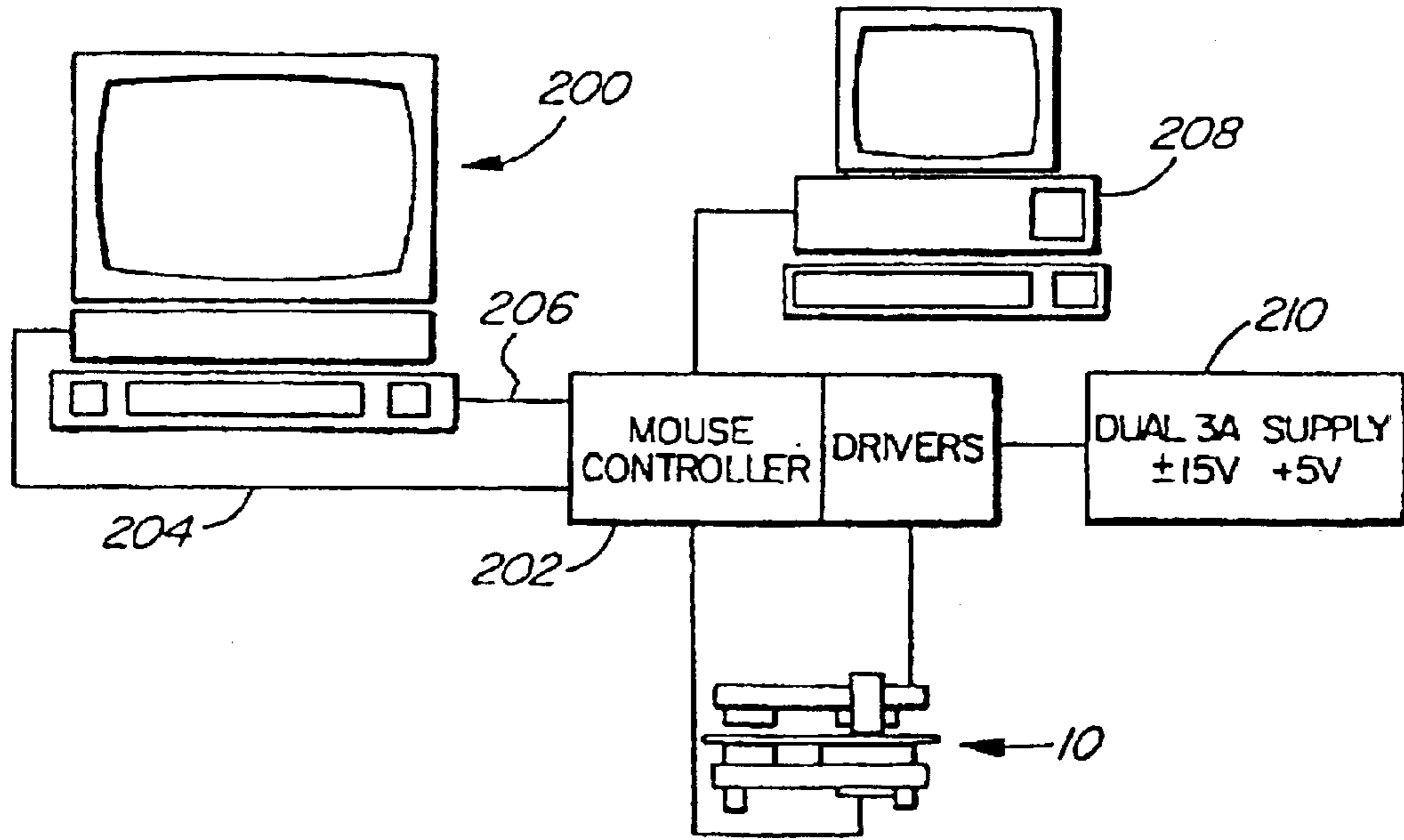


FIG. 11

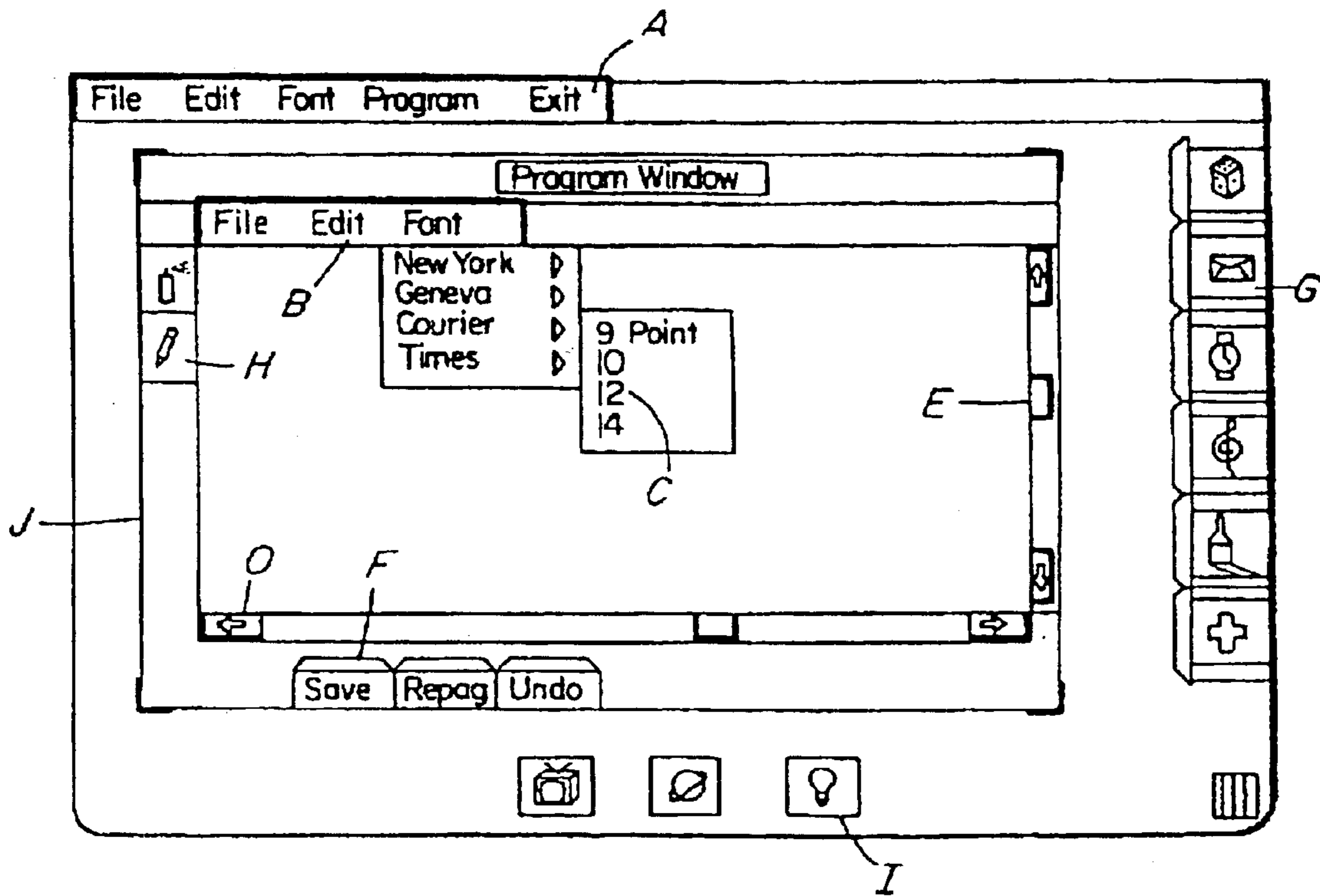


FIG. 12

# 1

## CONTROLLER

**Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.**

### FIELD OF THE INVENTION

The present invention relates to a controller. More particularly the present invention relates to an electromagnetic system for the application of force feedback to the moveable platform of a controller.

### BACKGROUND OF THE INVENTION

The concept of applying force feedback to a manual controller has been advanced and in fact implemented.

An article entitled Computing with Feeling by Atkinson et al in Computers and Graphics, Volume II, 1977, pp. 97 to 103, describes providing a "touchy, feely" and "touchy, twisty" to the operator so that the operator has the feel of the actions taking place. These force feedback sensations were created for molecular designs and models, etc.

A paper entitled Artificial Reality with Force Feedback; Development of Desktop Virtual Space and Compact Master Manipulator in Siggraph, Dallas, Aug. 6-10, 1990. Iwata describes a force feedback system with a human interface for manipulation of mock ups of solid objects and a paper entitled Creating an Illusion of Feel; Control Issues and Force Display, Sep. 16, 1989 Ouh-Young et al. describes the use of force feedback to create an illusion of feel. The National Aeronautics and Space Administration in an Abstract publication NASA Technology Transfer Division-Force Feedback Control May 1990 describes the use of force feedback to repel the controller and create the illusion the cursor should not cross boundaries of images, or that the cursor is attracted toward a point and to guide the operators hand in following a straight line or even along a curve.

To advance further the feedback to the operator requires control of the element manipulated by the operator, e.g. the joystick.

U.S. PAT. NO. 3,919,691 issued Nov. 11, 1975 to Noel discloses gantry mounted platform movement which is controllable in two mutually perpendicular directions by electromagnetic motors and cable or belt drives to the gantry system to impede the movement of the control platform in the two mutually perpendicular directions.

U.S. PAT. NO. 4,868,549 issued Sep. 19, 1989 to Affinito et al applies brakes to a ball in two mutually perpendicular directions. The brakes are operated by a computer to provide force feedback means to resist motion of the mouse or cursor.

### BRIEF DESCRIPTION OF THE PRESENT INVENTION

It is an object of the present invention to provide a control which permits the effective application of x, y (or z) force feedback to impede or direct movement of the hand control in the x,y (or z) direction.

Broadly the present invention relates to a controller comprising a base, a platform, means for mounting said platform for a range of movement in a plane of at least 1/2 inches (12.5 mm) in each of two different directions, a first magnetic force applying means including a first magnet means mounted on said base and a first cooperating magnetic force generating means mounted on and moveable with

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said platform in position to interact with said first magnet means, a second magnetic force applying means including a second magnet means mounted on said base and a second cooperating magnetic force generating means mounted on and moveable with said platform in a position to interact with said second magnet means, said first force applying means being positioned and constructed to controllably apply selected forces to said platform in one of said two directions and said second force applying means being constructed and positioned to controllably apply selected forces to said platform in the other of said two directions and control means to selectively control said first and said second force applying means to generate said selected forces.

Preferably said two directions will be mutually perpendicular.

Preferably said controller will further comprise a sensor means for sensing the position of said platform relative to said base.

More preferably said sensor means will comprise a transparent grid mounted on and moveable with said platform and a light source and a detector means fixed relative to said base in positions wherein light from said source passes through said grid and is detected by said detector means

Preferably said first cooperating magnet force generating means including a first coil means position to interact with said first magnet means when a current is applied to said first coil means, and said second magnetic force generating means including a second cooperating coil means in a position to interact with said second magnet means when a current is applied to said second coil means, said first magnet means and said first cooperating coil means of said first force applying means being shaped and positioned so that in any position of said platform within said range said coil may be controlled to apply said selected force between each of said first and second cooperating coil means and its respective magnet means and wherein said control means selectively applies current to said first and said second cooperating coil means to generate said selected forces.

It is also preferred that the projected area of a field generated by said first magnet means onto said first cooperating coil means is substantially constant so that the application of a selected current to said first cooperating coil means generates the same force between said first magnet means and said first cooperating coil means regardless of the position of said platform within said range of movement, said second magnet means and said second cooperating coil means of said second force applying means being shaped and positioned so that in any position of said platform within said range the projected area of a field generated by said second magnet means onto said second cooperating coil means is substantially constant so that the application of a selected current to said second cooperating coil means generates the same force between said second magnet means and said second cooperating coil means regardless of the position of said platform within said range.

Preferably said first cooperating coil means will comprise a first elongated substantially planar coil having its major axis extending substantially parallel to said plane and to one of said pair of mutually perpendicular directions and said second cooperating coil means will comprise a second elongated substantially planar coil having its major axis substantially parallel to said plane and said other of said mutually perpendicular directions.

Preferably said first magnet means and said second magnet means each will comprise a pair of permanent magnet

means, one permanent magnet means of each said pair located on one side of its said cooperating coil means and the other permanent magnet means of each said pair of permanent magnet means located on the side of its said cooperating coil means opposite its respective said one permanent magnet means.

Preferably each said permanent magnet means is configured with its magnetic poles facing in opposite directions and with their polar axes substantially parallel to the plane of said planar coils.

More preferably said polar axis of each said permanent magnet means is substantially parallel to said major axis of its respective cooperating planar coil.

Preferably said means for mounting will comprise gantry means

#### BRIEF DESCRIPTION OF THE DRAWINGS

Further features, objects and advantages will be evident from the following detailed description of the preferred embodiments of the present invention taken in conjunction with the accompanying drawings in which:

FIG. 1 is an exploded schematic illustration of the main component of the controller of the present invention.

FIG. 2 is an exploded view illustrating how the platform is mounted.

FIG. 3 is an exploded view of one pair of cooperating magnets and cooperating coil.

FIG. 4 is an exploded view of multi-layered planar actuator coil forming the electromagnet.

FIG. 5 is a schematic exploded illustration of the permanent magnetic the cooperating coil with the plot of field strength of the permanent magnets applied thereto.

FIG. 6 is an exploded view of the handle which may be used with a mouse of the present invention.

FIG. 7 is a section through the handle of FIG. 6 illustrating the construction of the actuator for the tactile element.

FIG. 8 is a schematic illustration of a hand controller or joystick that may be used in place of the control button of the controller.

FIG. 9 is an exploded view similar to FIG. 1 but illustrating the incorporation of a z direction controller.

FIG. 10 is an isometric illustration of the z controller.

FIG. 11 is a schematic illustration of the control system of the present invention.

FIG. 12 is an illustration of a typical program window that would be shown on a model illustrating some of the applications to which the present invention may be applied.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

The controller 10 illustrated in FIG. 1 includes a base element 12 and a cover 13 between which a platform 14 is mounted on a mounting system 16 that may take any suitable form, and in the illustrated embodiment is in the form of a gantry system 16 mounting the platform 14 from the base 12. The mounting system 16 permits of the platform 14 to move in two mutually perpendicular directions (as will be described in more detail hereinbelow).

A suitable controller or handle 18 having a push button switch 20 (used in a conventional manner of a typical mouse) is mounted on the platform 14.

The controller or handle 18 may also be provided with a tactile system which through movement of the tactile feed-

back element 22 may be used to apply pressure to the operator or used tin reverse to control an operation (as will be described hereinbelow).

The gantry 16 is more clearly indicated in the exploded view of FIG. 2. As illustrated it comprises a pair of similar one degree of freedom sliding frame units 24 and 26. The first frame unit 24 consists of parallel mounting bars 28 and 30 fixed to the base 12 and a pair of parallel rods 32 and 34 extending between and perpendicular to the mounting 28 and 30. A pair of spaced substantially parallel bars 36 and 38 extend substantially to and are slidable mounted on the rods 32 and 34 via guiding aperture 40 and 42 to permit the bars 36 and 38 to slide therealong.

The bars 36 and 38 of the first frame element 24 are held in spaced relationship by a pair of end mounting bar 44 and 46 which act in the same manner as the bars 28 and 30 but to mount a second pair of parallel mounting rods 48 and 50 oriented substantially perpendicular to the rods 32 and 34.

These rods 48 and 50 mount a second pair of parallel bars 52 and 54 similar to the bars 36 and 38 and provided with guiding holes 56 and 58 for movement of the bars 52 and 54 along the rods 48 and 50 so that the second frame unit 26 slides in the direction perpendicular to the direction in which the first frame unit 24 slides. The platform 14 is mounted on the second frame 26, i.e. is fixed to the bar 52 and 54.

The exploded view of FIG. 2 will also be used to explain the operation of the position sensor which determines the position of the platform 14 relative to the base 12. In the FIG. 2 illustration the position of the platform 14 is determined using the grid or mesh 60 of mutually perpendicular uniformly spaced lines that influence the transmission of light through the grid in a manner different from the spaces between the lines. The lines of the grid 60 are preferably oriented so that one set of parallel lines is parallel to the rods 32 and 34 and the other set is parallel to the rods 54 and 56. The grid 60 is the operative part of the platform 14 required to determine position.

Fixed to the top cover 13 is a suitable light source 62 which projects a beam of light 64 through the grid 60 onto a detector 66 fixed to the base 12. It will be evident that as the grid 60 is moved with the platform 14, each element (line) of the grid disrupts the light beam 64 as that element (line) traverses the beam 64. The disruption is sensed by the optical detector 66 which detects movements in the two mutually perpendicular directions.

The detector system or position detecting system described above may be replaced by any other suitable position detector.

The force applying actuators 70 or 72 (of FIG. 1) are essentially the same but are oriented in the controller 10 in mutually perpendicular relationship to the other. These actuators 70 and 72 control force applied to the platform 14. Each is composed of a pair of permanent magnets 74 and 76 fixed to the base 12 and cover 13 respectively and a flat or planar coil 90 mounted on the platform 14 and interposed between the fixed magnets 74 and 76. The actuators 70 and 72 are constructed essentially the same and thus like reference numerals have been used to illustrate like parts of the respective actuators 70 and 72.

The stationary magnet assemblies 74 and 76 are each composed of a pair of permanent magnets 78 and 80 mounted on a return plate 82 which magnetically interconnects the magnet 78 and 80.

In the arrangement illustrated in FIG. 3, the magnetic field between the corresponding magnets 78 of each pair of stationary magnets 74 and 76 in each of the actuators 70 and

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72 extends as indicated at 84 (upward in FIG. 3) while field between the corresponding magnets 80 of each pair of stationary magnets 74 and 76 in each of the actuators 70 and 72 extend in the opposite direction as indicated at 86 (downward).

Each of the actuators 70 and 72 includes an actuator coil 90 (eg. a Lorentz voice coil) mounted on-with the platform in a position to cooperates with the magnet 74 and 76, of its respective actuator 70 and 72. The coil(s) 90 as schematically illustrated in FIG. 4 is formed by interconnected coil winding 92, 94, 96 and 98 (only 4 shown) each embedded in its own coil plate 92A, 94A, 96A, and 98A respectively. Electrical power may selectively be introduced to the outer turns of the upper and lower windings 92 and 98 as indicated by the leads 100 and 102 and the windings are electrically interconnected via jumpers 104, 106, 108. The jumper 104 connects the inner turn of winding 92 with the inner turn of winding 94, the jumper 106 connects the outer turn of winding 94 with the outer turn, of winding 94 and the jumper 108 interconnects the inner turn of winding 96 with the inner turn of winding 98 so that the current travels in the same direction around each of the windings 92, 94, 96 and 98 and generates reinforcing lines of flux. The windings, shown in the exploded view of FIG. 5 could be manufactured directly on a printed circuit board which would obviously also serve as coil plate. If necessary a multi-layered print circuit board that could be used to increase the amount of current.

In a particular example of the actuator coil constructed as shown in FIG. 3 the coil 90 had a thickness of approximately 2.5mm and there was a clearance of approximately 1.25mm between the coil 90 and each of the magnets 74 and 76 (it is preferred to make the clearance smaller than this i.e. as small as possible or practical). The width W of each of the magnets 78 and 80 of this specific example were about 17mm while the gap G between the two magnets 78 and 80 was about 3mm so that the total width of the magnet 74 and 76 was 37mm.

The width  $W_c$  of each side 87 and 89 on opposite sides of the core 91 of the wound coil 90 in the example shown in FIG. 3 was 17mm and the length of the opening as indicated by the dimension L was 48mm to accommodate the axial displacement of the coil 90, i.e perpendicular at the arrows 110 and 112 which indicate the direction of force applied when the coil 90 is active by current flow in one direction or the other as will be described below.

The widths W and  $W_c$  and the width of the core 91 are coordinated to ensure that at all times the total projected area of the permanent magnets 78 and 80 onto the coil 90 remains constant over the range of movement of the coil 90 which is depicted by the dotted line 114.

The size of the coils 90 particularly their longitudinal axes have a significant influence on the range of movement of the platform 14 relative to the based. This range preferably will be at least 1/2 inch (12.5mm) in each of the two mutually perpendicular directions and preferably at least 1 inch (25mm) in each of those directions.

FIG. 5 illustrates the electromagnetic field that will be generated by each of the magnet 74 and 76 measured in the plane of the coil 90 mounted on the platform 14.

The width W of the permanent magnet 80 will be the same for each of the magnets 80 and for the magnets 78 and the spacing G therebetween will also be the same, but may be selected differently depending on how actuator coil 90 mounted on the platform 14 is constructed. The dimensions of the coil 90, i.e. width  $W_c$  and length L as above indicated define the permitted movement of the platform 14. In the

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arrangement illustrated in FIG. 3, in the neutral position, i.e. the position where the light beam 64 is in the centre of the grid 60, the magnets 78 and 80 are positioned as indicated in dotted lines at 88, in the centre of the coil 90 with half (1/2) of the projected area of each of the magnets 78 and 80 overlapping respectively with sides 87 and 89 of the coil 90.

It will be apparent that in this position if the platform is moved in the directions of the 110 or 112 the same amount of one of the projected areas moves from overlapping with the coil 90 into the core space 91 that moves from the space 91 into the coil 90 and that movement in the axial direction of the coil 90 does not change the relative amount of area directly subjected to the magnetic field of the permanent magnets 78 and 80.

Thus a given current through the coil 90 in one direction develops the same force regardless of the position of the platform within its range of movement. If the platform is moved so that the projections 88 extend beyond the length L in either direction, the total force generated between the coil 90 and the magnets 74 and 76 will not remain constant.

For the illustration in FIG. 3 the gap G is relatively narrow and the width of the core 91 of the coil 90 is relatively wide since the magnets 78 and 80 project into the core 91. In an alternative arrangement as illustrated in FIG. 1 the magnets 78 and 80 have been spaced farther, i.e. the gap G has increased dramatically so that half of magnet 78 project outside of the coil 90 as does half of the magnet 80. The arrangement of FIG. 1 and 5 is preferred as it permits using a narrower coil 90.

The width of the coil as indicated at  $W_c$  defines the amount of movement that can be accommodated in the direction of the arrows 110 and 112 while maintaining the constant force application for a given current. In the FIG. 3 arrangement the effective maximum width  $W_c$  of each side of the coil 90 should not exceed.

$$W_c(\text{MAX})=W+G$$

as if this width is exceeded movement of the platform in the directions 110 or 112 might result in more projected area of the magnets 78 and 80 onto the coil 90.

FIG. 5 shows the magnetic field form the permanent magnets 78 and 80 via the dash line 93, it being a maximum directly between the aligned magnets 78 or 80.

In operation with a given current i in the conductor of the coil 90 with a differential element length dl, a differential force dF will be exerted on the conductor when crossed by the magnetic field B generated by the magnet 74 and 76. The mathematical relationship is

$$dF=i \, dl \times B.$$

By integrating over the portions of the coil 90 that intersect the effective flux areas of the permanent magnets 74 and 76, a total force F is seen to act along one axis with its orientation dictated by the direction of the current. It follows that the x and y direction actuation forces on the coil 90 can be controlled by two independent, bi-directional currents. An embedded micro-controller 67 (see FIG. 1) may be used for controlling the motion sensing and force actuation of the system. This micro-controller determines the movement of the platform as above described by the interruption of the beam 64 by the line grid. When motion is detected, the micro-controller 67 sends the appropriate information packet through a connection to the computer's mouse port

where it is interpreted by that system's mouse driver in the same way as it would for a common mouse.

After calculating the position of the platform **14**, the micro-controller's control program also calculates any necessary feedback forces and causes their actuation by turning on current drivers that excite one or both of the x and/or y direction coils **90**.

While it is preferred to construct the platform **14**, coils **90** and permanent magnets **47** and **76** as above described so that anywhere within the normal range of movement of the platform **14** a given current to the coils **90** imparts the same force to the platform **14** in the selected direction, it is also possible to construct the coils **90** and magnets **74** and **76** so that the same projected area of the permanent magnets **74** and **76** onto the coils **90** does not occur throughout the complete range of movement of the platform **14** relative to the base **12** and to vary the current applied to the coils **90** based on the relative position of each of the coils **90** with its respective permanent magnets **74** and **76** so that the current will be adjusted to generate the desired force by applying a current that will obtain that desired force at that relative positioning of the coil **90** and its respective magnets **74** and **76**. Depending on the shape and size of the coils **90** this may require active adjustment (for example on the basis of lookup tables) based on limited movements of the platform **14** relative to the base **12** and for that reason for previously described arrangement permitting the use of a constant current for a given force anywhere within the normal range of relatively movement between the platform **14** and the base **12** is preferred.

The mouse handle **18** is shown in exploded view in FIG. **6** and includes as above described an actuator button **20** and a tactile element **22**. The button **20** actuates a micro switch **118** while the tactile element **22** is controlled by an E-core type magnet **122** with a coil as schematically indicated at **124**.

The structure of the tactile element is more clearly shown in FIG. **7** and includes an E-core magnet **122** with a coil **124** wrapped around its inner leg which is positioned to cooperate with a permanent magnet **126** mounted on the tactile element **22**.

A pair of springs **128** and **130** tend to hold the tactile element in its lower most position as illustrated i.e. closest to the core **122**, however when the coil is activated the repulsion of the magnet **126** from the core **122** and the coil **124** is stronger than the tension in the springs **128** and **130** so that the tactile element moves upwardly away from the core **122** with the amount of movement being dependent on the current in the coil **124**.

The position of the tactile element **22** is such that it contacts with the hand of the user and when activated applies pressure thereagainst, the pressure being proportional to the amount of current passing through the coil **124**.

Other types of handles may be used if desired, for example, the control handle **131** in FIG. **8**, which takes the form of a joystick control may also be used and may be provided with further controller buttons as schematically indicated at **132** and further tactile elements as indicated at **134**, **136** and **138** on the joystick **140**. Tactile elements may be operated in a similar manner to the tactile element **22** described above and the control elements **132** may take the form of pressure switches or the like.

In the event a controller for controlling three degrees of freedom is required, the handle **18** or **140** may be replaced by or modified to provide z axis control, for example instead of the tactile element **22** functioning as a tactile element it could be used as a z controller by providing a suitable

position sensor to sense the position of the element **22** when it is displaced from a rest position or alternatively as a bi-stable switch for limited z direction control.

A z direction controller **142** is illustrated in FIG. **9**. This controller **142** is fixed to the platform **14** enclosed by a top **13A** replacing and similar to the top **13** but modified to accommodate the z direction controller **142**.

In the embodiment illustrated in FIG. **9**, like reference numerals have been used to indicate like parts of those in FIG. **1**.

The configuration of the coil **90** and of the permanent magnet **74** and **76** in FIGS. **1** and **9** are significantly different, in the FIG. **9** arrangement the permanent magnets in neutral position project to the outside of the sides **87** and **89** while in FIG. **3** they were on the inside.

The z direction controller **142** is composed of a frame **144** which is fixed to the platform **14**. Mounted to the frame **144** are parallel rods **146** and **148** fixed at their upper ends to the bar **150** and their bottom ends to the cross base **152**. The rods **146** and **148** are perpendicular to the rods **32,34,36** and **38**. A platform **154** on which is mounted a coil plate **156** similar to the coil plate **90** described hereinabove is slidable mounted on the rods **146** and **148** via bars **170** and **172** with suitable opening to receive the rods **146** and **148** (similar to the manner in which the platform **14** is mounted).

The coil plate **156** cooperates with a pair of permanent magnets **158** (only one shown) equivalent to the permanent magnets **74** and **76** described hereinabove.

An LED or other light source **160** projects light through encoding **162** which is provided with a plurality of uniformly spaced horizontal lines between which the light from the source **160** projects so that movement of these lines disrupts the light from the source **160**. Light passing through the grid or encoder **162** is focused via lens **164** onto sensor or photo detector **166** which generates a signal substantially in the same manner as the encoder **66** and **67** for the platform **14**.

The platform **154** is provided with a handle **168** moveable in the z direction on the rod **146** and **148** and is used to manipulate the platform **14**.

Force feedback is applied to the handle **18**, **140** or **168** is generated by programming a computer. For demonstration purposes the configuration shown in FIG. **11** was used wherein a first display station computer **200** was interconnected with a mouse controller **202** by two lines of serial communication **204** and **206** respectively specifically a connection to the mouse port for supplying the work station with mouse motion data and a connection from a serial port for receiving commands and screen information from the work station.

A second computer **206** was connected to the mouse controller **202** and was used as a monitor for loading new code into memory on the controller board. A suitable power supply **210** provides power to the driver **212** for the controller **10**.

The software is running on both the computers **200** and **208** so the responsibilities of the two units must be properly divided.

Preferably the mouse **202** will send movement and button status data to the computer **200** where software calculates the desired forces for that particular pointer location and sends that force information to the micro controller which in turn drives the coils **90**, **124** and **156** as required. However, this requires a very high powered computer and therefore to simplify to permit operation with the equipment available the computer **200** responsibilities were limited to handling the usual x window events, process input to maintain graphic

interface and to initiate a synchronous transmission of non-real time commands to the micro controller when necessary. The micro controller is given the responsibility of doing the mouse position sensing to control movement and the transmission of mouse status data to the host mouse port and at the same time respond to commands from the host **200** and store in memory the locations of icon, windows, buttons, etc. that are activated on the display and to interactively calculate the necessary feedback forces with respect to pointer or cursor positions during control movements.

FIG. **12** shows an example of a graphic user interface that could be augmented with tactile and kinesthetic interface using the present invention. The various lettered designations illustrate some of the features that may be obtained using the force feedback of the present invention.

A. The mouse may be programmed to constrain the cursor for movement along a straight edge.

B. indicates a menu bar that may be programmed as kinaesthetically stable place when it is approached from below so that the user can move the pointer rapidly in the direction of the menu bar from below and when it reaches the menu bar force feedback applied to the control handle to stop the motion of the controller and thus of the pointer.

The menu bar itself may be provided with bi-stable tactile elements to indicate when the pointer moves from one menu item to the next.

C. indicates a vertical menu. In this system the mouse could be set to permit the pointer to move only vertically up or down the menu.

D. The scroll bar shown at D may be supplemented with force feedback applied to the arrow used for the scrolling process by allowing the user to move faster and be more carefree when trying to position the pointer over the arrow. This can be done by creating forces at the sides on the arrow that prevent the pointer from overshooting, i.e. it would impede the mouse as it moves across the arrow.

The force feedback system could be also be used to actuate the computer rather than the button or switch mounted on the handle EG.switch **20**. The mouse would simulate a button press in its transmission to the computer whenever the force with which the user pushes against one of the sides of the arrow exceeds a threshold.

E. shows a thumb type scroll bar which is similar to the arrow type scroll bar and to which force feedback could be applied to form a stable position in the bar and prevent the pointer from overshooting and constrain the pointer from going beyond the thumb opening. After the pointer is in position within the thumb opening pressing the pointer against the top or bottom of the thumb opening, the thumb would follow the motion of the pointer.

Furthermore, as the thumb is moved a damping force could be added and the motion direction, giving the user feedback in the form of a viscous drag sensation and when the thumb has reached the limit of its range appropriate force could be applied to the handle.

F. Command Soft button manipulatable by movement of the pointer or curse to initiate command i.e. soft buttons that may be pressed by the pointer and the tactile sense of pressing a button transferred back to the controller handle so that the feel of pressing a button.

G. shows further examples of soft buttons that could be used in a manner similar to icons and incorporate in the software a force gravitational scheme to facilitate user arriving at the button.

H. shows tactile regions wherein examples of specific tools may be selected The use of a bi-stable tactile feedback system could be employed to make user selection of the desired tool more quick and accurate.

I. indicates a system wherein gravitational force may be applied to draw the cursor pointer to the icon when it comes within a certain preselected distance of the icon.

J. demonstrates a window boundary wherein force feedback would be designed to prevent the pointer or cursor from traversing such a boundary or apply force when the window is entered or exited.

It will be apparent that by programming, control of the power of the coils **90**, **122** and **156** may be accomplished making it possible to apply any desired force feedback to the handle, i.e. the position of the handle corresponds with the position of the pointer which provides the necessary information to apply force feedback coordinated with the position of the pointer on the monitor.

The coils **90** throughout description have been defined as having their longitudinal axes mutually perpendicular which is the preferred arrangement, but it will be apparent with appropriate software modification it is possible to arrange the coils differently i.e. so their axes extend in different directions that are neither parallel nor perpendicular.

Having described the invention, modifications will be evident to those skilled in the art without departing from the spirit of the invention as defined in the appended claims.

We claim:

**[1.** A controller comprising a base, a platform, means for mounting said platform for a range of movement in a plane in each of two different directions, a first magnetic force applying means including a first magnet means mounted on said base and a first cooperating magnetic force generating means mounted on and moveable with said platform in position to interact with said first magnet means, a second magnetic force applying means including a second magnet means mounted on said base and a second cooperating magnetic force generating means mounted on and moveable with said platform in a position to interact with said second magnet means, said first and said second magnet means being fixed relative to each other on said base and said first and said second cooperating magnet force generating means being fixed relative to each other on said platform, said first force applying means being positioned and constructed to controllably apply selected forces to said platform in one of said two different directions and said second force applying means being constructed and positioned to controllably apply selected forces to said platform in the other of said two different directions and control means to selectively control said first and said second force applying means to generate said selected forces.]

**[2.** A controller as defined in claim **1** wherein said two directions are mutually perpendicular.]

**[3.** A controller as defined in claim **1** further comprising a sensor means for sensing the position of said platform relative to said base.]

**[4.** A controller as defined in claim **3** wherein said sensor means comprises a transparent grid mounted on and moveable with said platform and a light source and a detector means fixed relative to said base in positions wherein light from said source passes through said grid and is detected by said detector means.]

**[5.** A controller as defined in claim **2** further comprising a sensor means for sensing the position of said platform relative to said base.]

**[6.** A controller as defined in claim **5** wherein said sensor means comprises a transparent grid mounted on and moveable with said platform and a light source and a detector means fixed relative to said base in positions wherein light from said source passes through said grid and is detected by said detector means.]



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[7. A controller as defined in claim 2 wherein said first cooperating magnet force generating means including a first coil means position to interact with said first magnet means when a current is applied to said first coil means, and said second magnetic force generating means including a second cooperating coil means in a position to interact with said second magnet means when a current is applied to said second coil means, said first magnet means and said first cooperating coil means of said first force applying means being shaped and positioned so that in any position of said platform within said range said coil may be controlled to apply said selected forces between each of said first and second cooperating coil means and its respective magnet means and wherein said control means selectively applies current to said first and said second cooperating coil means to generate said selected forces.]

[8. A controller as defined in claim 7 wherein the projected area of a field generated by said first magnet means onto said first cooperating coil means is substantially constant so that the application of a selected current to said first cooperating coil means generates the same force between said first magnet means and said first cooperating coil means regardless of the position of said platform within said range of movement, said second magnet means and said second cooperating coil means of said second force applying means being shaped and positioned so that in any position of said platform within said range the projected area of a field generated by said second magnet means onto said second cooperating coil means is substantially constant so that the application of a selected current to said second cooperating coil means generates the same force between said second magnet means and said second cooperating coil means regardless of the position of said platform within said range.]

[9. A controller as defined in claim 8 wherein said first cooperating coil means comprises a first elongated substantially planar coil having its major axis extending substantially parallel to said plane and to one of said pair of mutually perpendicular directions and said second cooperating coil means comprises a second elongated substantially planar coil having its major axis substantially parallel to said plane and said other of said mutually perpendicular directions.]

[10. A controller as defined in claim 5 wherein said first cooperating magnet force generating means including a first coil means position to interact with said first magnet means when a current is applied to said first coil means, and said second magnetic force generating means including a second cooperating coil means in a position to interact with said second magnet means when a current is applied to said second coil means, said first magnet means and said first cooperating coil means of said first force applying means being shaped and positioned so that in any position of said platform within said range said coil may be controlled to apply said selected forces between each of said first and second cooperating coil means and its respective magnet means and wherein said control means selectively applies current to said first and said second cooperating coil means to generate said selected forces.]

[11. A controller as defined in claim 10 wherein the projected area of a field generated by said first magnet means onto said first cooperating coil means is substantially constant so that the application of a selected current to said first cooperating coil means generates the same force between said first magnet means and said first cooperating coil means regardless of the position of said platform within said range of movement, said second magnet means and said second cooperating coil means of said second force applying means

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being shaped and positioned so that in any position of said platform within said range the projected area of a field generated by said second magnet means onto said second cooperating coil means is substantially constant so that the application of a selected current to said second cooperating coil means generates the same force between said second magnet means and said second cooperating coil means regardless of the position of said platform within said range.]

[12. A controller as defined in claim 11 wherein said first cooperating coil means comprises a first elongated substantially planar coil having its major axis extending substantially parallel to said plane and to one of said pair of mutually perpendicular directions and said second cooperating coil means comprises a second elongated substantially planar coil having its major axis substantially parallel to said plane and said other of said mutually perpendicular directions.]

[13. A controller as defined in claim 6 wherein said first cooperating magnet force generating means including a first coil means position to interact with said first magnet means when a current is applied to said first coil means, and said second magnetic force generating means including a second cooperating coil means in a position to interact with said second magnet means when a current is applied to said second coil means, said first magnet means and said first cooperating coil means of said first force applying means being shaped and positioned so that in any position of said platform within said range said coil may be controlled to apply said selected forces between each of said first and second cooperating coil means and its respective magnet means and wherein said control means selectively applies current to said first and said second cooperating coil means to generate said selected forces.]

[14. A controller as defined in claim 13 wherein the projected area of a field generated by said first magnetic means onto said first cooperating coil means is substantially constant so that the application of a selected current to said first cooperating coil means generates the same force between said first magnet means and said first cooperating coil means regardless of the position of said platform within said range of movement, said second magnet means and said second cooperating coil means of said second force applying means being shaped and positioned so that in any position of said platform within said range the projected area of a field generated by said second magnet means onto said second cooperating coil means is substantially constant so that the application of a selected current to said second cooperating coil means generates the same force between said second magnet means and said second cooperating coil means regardless of the position of said platform within said range.]

[15. A controller as defined in claim 14 wherein said first cooperating coil means comprises a first elongated substantially planar coil having its major axis extending substantially parallel to said plane and to one of said pair of mutually perpendicular directions and said second cooperating coil means comprises a second elongated substantially planar coil having its major axis substantially parallel to said plane and said other of said mutually perpendicular directions.]

[16. A controller as defined in claim 9 wherein said first magnet means and said second magnet means each comprises a pair of permanent magnet means, one permanent magnet means of each said pair located on one side of its said cooperating coil means and the other permanent magnet means of each said pair of permanent magnet means located on the side of its said cooperating coil means opposite its respective said one permanent magnet means.]

[17. A controller as defined in claim 16 wherein each said permanent magnet means comprises a pair of permanent magnets arranged in spaced parallel relationship with their magnetic poles facing in opposite directions and with their polar axes substantially parallel to the plane of said planar coils.]

[18. A controller as defined in claim 17 wherein said polar axis of each said permanent magnet means is substantially parallel to said major axis of its respective cooperating planar coil.]

19. An interface device for enabling a user to spatially navigate a displayed graphical menu with a displayed graphical pointer, said graphical menu having a plurality of menu elements, and for enabling said user to more easily select a menu element from said graphical menu by providing tactile feedback to said user when said graphical pointer is moved from a first menu element to a second menu element in said graphical menu, said interface device comprising:

(a) a handle to be manipulated manually by a user in at least two planar degrees of freedom;

(b) a z-axis actuator generating tactile sensations to be felt by said user, wherein said z-axis actuator applies forces to a user's hand only along a z-axis degree of freedom when current is flowed through a portion of said actuator, said z-axis degree of freedom being different from and substantially perpendicular to said two planar degrees of freedom;

(c) a sensor that produces a locative signal responsive to and corresponding with a motion of said handle in said at least two degrees of freedom;

(d) a button that produces a status signal in response to being pressed by said user; and

(e) an embedded microprocessor local to said interface device and coupled to said sensor, to said button, and to said actuator, said microprocessor performing:

sending handle movement data and button data to a host computer over a communication bus such that said host computer can update displayed pointer locations with respect to said displayed graphical menu,

receiving desired force values from said host computer, said desired force values correlated with particular pointer locations displayed by said host computer, and

controlling said z-axis actuator in accordance with said received desired force values so as to provide said tactile sensations to said user that are correlated with a location of said displayed graphical pointer displayed within said graphical menu.

20. An interface device as recited in claim 19 wherein said z-axis actuator imparts, said tactile sensations upon said handle along a z-axis orthogonal to said at least two planar degrees of freedom.

21. An interface device as recited in claim 19 wherein said handle is physically coupled to a support mechanism that is grounded and allows linear displacement between said handle and an origin.

22. An interface device as recited in claim 21 wherein said z-axis actuator is a flat coil actuator.

23. An interface device as recited in claim 22 wherein a magnet associated with said flat coil actuator is fixed with respect to said origin and wherein said flat coil actuator moves with respect to said origin.

24. An interface device as recited in claim 19 wherein said sensor is an optical sensor that includes an emitter and a detector.

25. An interface device as recited in claim 24 wherein said emitter moves when said handle is moved, projecting light upon said detector.

26. An interface device as recited in claim 25 wherein said detector detects motion of said emitter in two mutually perpendicular directions.

27. An interface device as recited in claim 19 further comprising a memory that stores values that are representative of a location of an image displayed by said host computer.

28. An interface device as recited in claim 27 wherein said location includes a location of an icon displayed by said host computer.

29. An interface device as recited in claim 19 wherein said handle is a joystick.

30. An interface device as recited in claim 19 wherein said handle is a mouse.

31. An interface device as recited in claim 19 wherein said embedded microprocessor receives display information from said host computer over said communication bus.

32. An interface device as recited in claim 19 wherein said tactile sensations include a viscous drag force.

33. An interface device as recited in claim 19 wherein said tactile sensations include an attractive force.

34. An interface device as recited in claim 34 wherein said attractive force is used to assist a user in positioning said displayed graphical pointer into said displayed graphical menu.

35. An interface device as recited in claim 19 wherein said embedded microprocessor receives code over a communication bus from said host computer and executes said code, said communication bus including a serial interface bus.

36. A device for use in conjunction with a host computer including a computer display, said host computer displaying a graphical environment including a displayed graphical pointer controlled by a user, said device comprising:

a handle to be manipulated manually by said user in at least two planar degrees of freedom;

a z-axis actuator to generate a tactile sensation to be felt by said user, said z-axis actuator applying forces to a hand of said user only along a z-axis degree of freedom when current is flowed through a portion of said z-axis actuator, said z-axis degree of freedom being different from and substantially perpendicular to said at least two planar degrees of freedom;

a sensor that produces a locative signal responsive to and corresponding with a position or motion of said handle in said at least two planar degrees of freedom;

a button that produces a status signal in response to being pressed by said user; and

a control electronics local to said device and coupled to said sensor and said actuator and said button, said control electronics performing the following:

sending handle movement data and button data to said host computer over a communication bus such that said host computer can update a displayed pointer location in said displayed graphical environment, receiving a force value from said host computer, said force value correlated with said updated displayed pointer location, and

controlling said z-axis actuator in accordance with said received force value so as to provide said tactile sensation to said user that is correlated with a location of said displayed graphical pointer displayed within said displayed graphical environment.

37. A device as recited in claim 36 wherein said control electronics include an embedded microcontroller.

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38. A device as recited in claim 37 wherein said embedded microcontroller runs a program contained, at least in part, in a memory coupled to said embedded microcontroller, and wherein said memory also stores location information which corresponds with image data from a computer display 5 coupled to said host computer.

39. A device as recited in claim 38 wherein said location information includes information relating to a location of an icon on said graphical display.

40. A device as recited in claim 38 wherein said location information includes information relating to a location of a 10 window on said graphical environment.

41. A device as recited in claim 38 wherein said location information includes information related to a location of a graphical button on said graphical environment.

42. A device as recited in claim 38 wherein said graphical 15 environment includes a cursor interacting with another object displayed on said computer display.

43. A device as recited in claim 42 wherein said cursor interacts with an icon image displayed on said computer 20 display.

44. A device as recited in claim 36 wherein said at least two planar degrees of freedom are linear degrees of free- 25 dom.

45. A device as recited in claim 36 wherein said control electronics calculates force feedback forces based on com- 25 mands received from said host computer.

46. A device as recited in claim 36 wherein said handle is moveable in a plane.

47. A device as recited in claim 46 wherein said handle is also moveable along a z-axis that is approximately perpen- 30 dicular to said plane.

48. A device as recited in claim 36 wherein said tactile sensation is applied to correspond with said displayed pointer interacting with a displayed graphical menu to enable said user to more easily select a menu item from said 35 displayed graphical menu by providing tactile feedback to said user when said displayed graphical pointer is moved from one menu item to a next menu item in said graphical menu.

49. A device as recited in claim 36 wherein said tactile 40 sensation is applied to correspond with said displayed pointer interacting with a displayed button.

50. A device as recited in claim 36 wherein said tactile sensation is applied to correspond with said displayed 45 pointer interacting with a displayed window.

51. A device as recited in claim 36 wherein said tactile sensation is applied to correspond with said displayed 50 pointer interacting with a displayed icon.

52. An interface device for use with a host computer displaying a graphical application on a display device, said 50 host computer displaying, executing, and updating graphical objects in a graphical environment in response to user manipulation of said interface device and commanding force feedback sensations in response to said user manipulation and in coordination with said graphical objects, said 55 graphical objects including a graphical pointer, said interface device comprising:

a physical object grasped and manipulatable by a user in two planar degrees of freedom;

at least one z-axis actuator coupled to said physical 60 object for receiving a force control signal and imparting forces along at least one degree of freedom of said physical object and in accordance with said force control signal, said forces applied along a z-axis 65 degree of freedom that is different from and substantially perpendicular to said two planar degrees of freedom;

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a sensor that detects motion of said physical object along said at least one degree of freedom and outputs signals relating to a position of said physical object;

a user-adjustable switch apparatus providing a state signal representing a state of said user-adjustable switch apparatus; and

a microprocessor local to said interface device, separate from said host computer, and coupled to said host computer, to said sensor, and to said switch apparatus, said microprocessor receiving

force values from said host computer, said force values correlated with particular locations of said graphical pointer in said graphical environment displayed by said host computer,

said state signal from said user-adjustable switch apparatus, and

said signals from said sensor,

said microprocessor executing a process in parallel with said displaying, executing, and updating graphical objects and providing said force control signal to said at least one z-axis actuator to impart said forces in accordance with said force values so as to provide tactile sensations to said user that are correlated with a location of said displayed graphical pointer.

53. The interface device as recited in claim 52 wherein said graphical objects include a displayed graphical menu, wherein said tactile sensations enable said user to more easily select a menu element from said displayed graphical menu by providing said tactile sensations to said user when said graphical pointer is moved from one menu element to a next menu element in said displayed graphical menu.

54. A method for controlling a force feedback interface device using a host computer, said force feedback interface device manipulated by a user, a display device coupled to said host computer displaying a graphical user interface including images and updating said graphical user interface in response to said manipulation of said force feedback interface device, said force feedback interface device conveying force feedback sensations to said user in response to said manipulations, said method comprising:

sending a position signal to said host computer, said position signal including information representative of a motion or position of a handle of said force feedback interface device in two planar degrees of freedom, said handle being physically manipulated by said user, wherein said host computer updates a location of a cursor within said graphical user interface in response to said position signal;

receiving a force value from said host computer with a microprocessor local to said force feedback interface device, said force value correlated with said location of said cursor; and

controlling a z-axis actuator in accordance with said received force value to provide a tactile sensation to said user that is correlated with said location of said cursor in said graphical user interface, said tactile sensation being applied to a hand of said user along a z-axis degree of freedom, said z-axis degree of freedom being different from and substantially perpendicular to said two planar degrees of freedom.

55. A method as recited in claim 54 wherein a sensor signal is input to said microprocessor, said microprocessor calculating said position signal based on said sensor signal, said microprocessor sending said position signal to said host computer.

56. A method as recited in claim 54 wherein said handle includes a joystick that can be moved by said user in two degrees of freedom.

57. A method as recited in claim 55 wherein said graphical user interface provides graphical objects for interfacing with an application program running on said host computer, said graphical objects including an icon, a window, and a menu.

58. A human-computer interface device for controlling a graphical cursor displayed by a host computer and for providing tactile feedback to a user in accordance with displayed interactions between said graphical cursor and other graphical objects displayed by said host computer, said interface device comprising:

a physical object to be moved by a user in two planar degrees of freedom;

one or more sensors that produce a locative signal responsive to and indicative of a position of said physical object in said two planar degrees of freedom;

a z-axis actuator that applies force to a hand of said user only along a z-axis degree of freedom when current is flowed through a portion of said z-axis actuator, said z-axis degree of freedom being different from and substantially perpendicular to said two planar degrees of freedom; and

a microprocessor separate from and in communication with said host computer, said microprocessor coupled to said one or more sensors and to said z-axis actuator, wherein said microprocessor receives desired force values from said host computer, said desired force values correlated with particular pointer locations displayed by said host computer, said microprocessor controlling current through said portion of said actuator in accordance with said desired force values.

59. An interface device as recited in claim 58 wherein said two planar degrees of freedom are x and y axes parallel to a flat surface on which said interface device rests and said z-axis degree of freedom is substantially perpendicular to said x and y axes.

60. An interface device as recited in claim 58 wherein said interface device is a mouse device and wherein said physical object is a mouse.

61. An interface device as recited in claim 58 wherein said z-axis actuator includes a wire coil through which said current is flowed.

62. An interface device as recited in claim 61 wherein said z-axis actuator includes a magnet core.

63. An interface device as recited in claim 62 wherein said magnet core is an E-core.

64. An interface device as recited in claim 62 further comprising a permanent spring coupled between said physical object and said actuator.

65. An interface device as recited in claim 58 wherein said one or more sensors is an optical encoder.

66. An interface device as recited in claim 65 wherein said one or more sensors is an encoder.

67. An interface device as recited in claim 58 wherein said z-axis actuator is controlled to indicate when said graphical cursor displayed by said host computer is moved from one displayed menu element to another displayed menu element.

68. An interface device as recited in claim 58 wherein said z-axis actuator is controlled to indicate when said graphical cursor displayed by said host computer crosses a window boundary.

69. An interface device as recited in claim 58 wherein said z-axis actuator is controlled to apply said force to said hand to indicate when said graphical cursor displayed on said host computer is positioned over a graphical element.

70. An interface device as recited in claim 58 wherein said actuator includes a portion that is moveable by said user along a z-axis control to said host computer.

71. An interface device as recited in claim 58 wherein a physical tactile element is physically coupled to said actuator and is moved to contact and apply pressure to said hand.

72. An interface device as recited in claim 71 wherein said physical tactile element applies pressure upon said hand by pressing upward on said hand when said current is flowed through said portion of said z-axis actuator.

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : RE 40,341 E  
APPLICATION NO. : 09/307023  
DATED : May 27, 2008  
INVENTOR(S) : Septimiu Edmund Salcudean et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Page 3, second reference, first column, phrase "ANS Topical Mfg." should read --ANS Topical Mtg.--

Page 4, second reference, second column, word "Demonsdtrator" should read --Demonstrator--

Page 4, fourth reference, second column, word "Bullein" should read --Bulletin--

Column 13, Line 44, phrase "said host computer," should read --said host computer;--

Column 18, Line 14, phrase "is an optical encoder" should read --is an optical sensor--

Column 2, Line 24, phrase "said detector means" should read --said detector means.--

Column 3, Line 15, word "means" should read --means.--

Column 4, Line 15, phrase "end of mounting bar 44 and 46" should read --end of mounting bars 44 and 46--

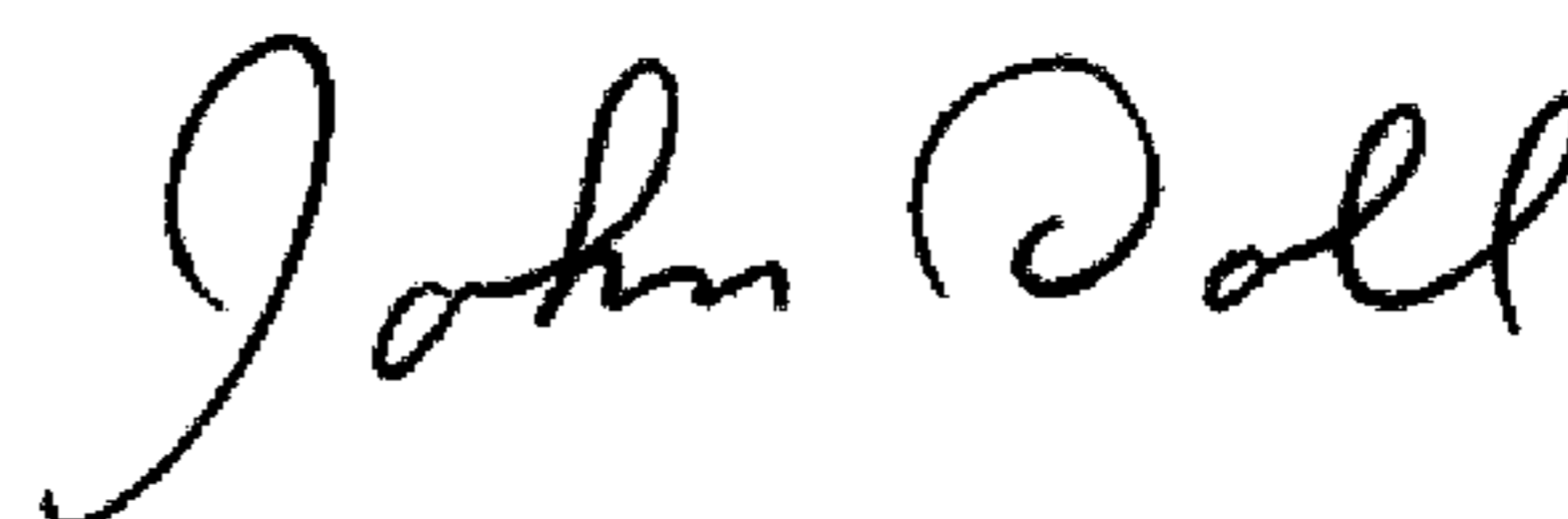
Column 4, Line 28, word "platform" should read --platform--

Column 9, Line 65, phrase "may be selected The use of" should read --may be selected.

The use of--

Signed and Sealed this

Third Day of March, 2009



JOHN DOLL

*Acting Director of the United States Patent and Trademark Office*