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(54) **DRAIN SAFETY AND PUMP CONTROL DEVICE WITH VERIFICATION**

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(60) Provisional application No. 60/817,473, filed on Jun. 29, 2006.

Publication Classification

(51) **Int. Cl.**
F04B 49/00 (2006.01)

(52) **U.S. Cl.** **137/565.11**; 417/1; 700/90

(57) **ABSTRACT**

A drain protection device and pump controller for pools, spas, fountains and other fluid containment and circulation systems has a vacuum sensor for sensing a level of vacuum present in the suction conduit leading to the pump(s). The vacuum level is monitored by a computer that controls a vent valve and the pump(s) to reduce the vacuum exerted at a drain. Vacuum criteria may be adjustable and empirically based. Control and monitoring may be verified.

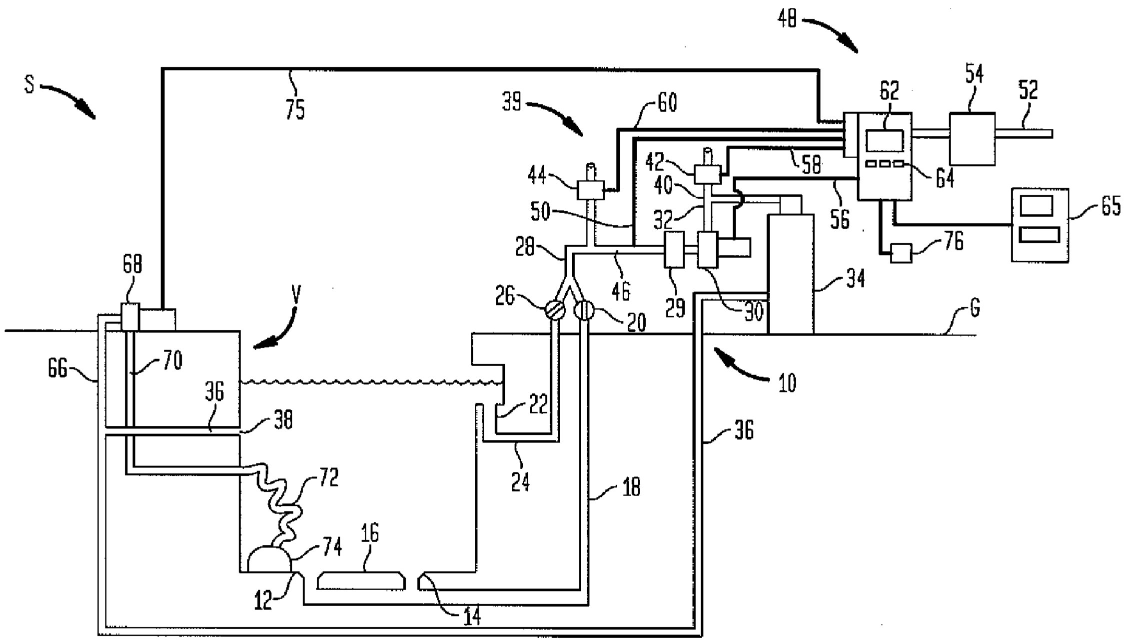


FIG. 1

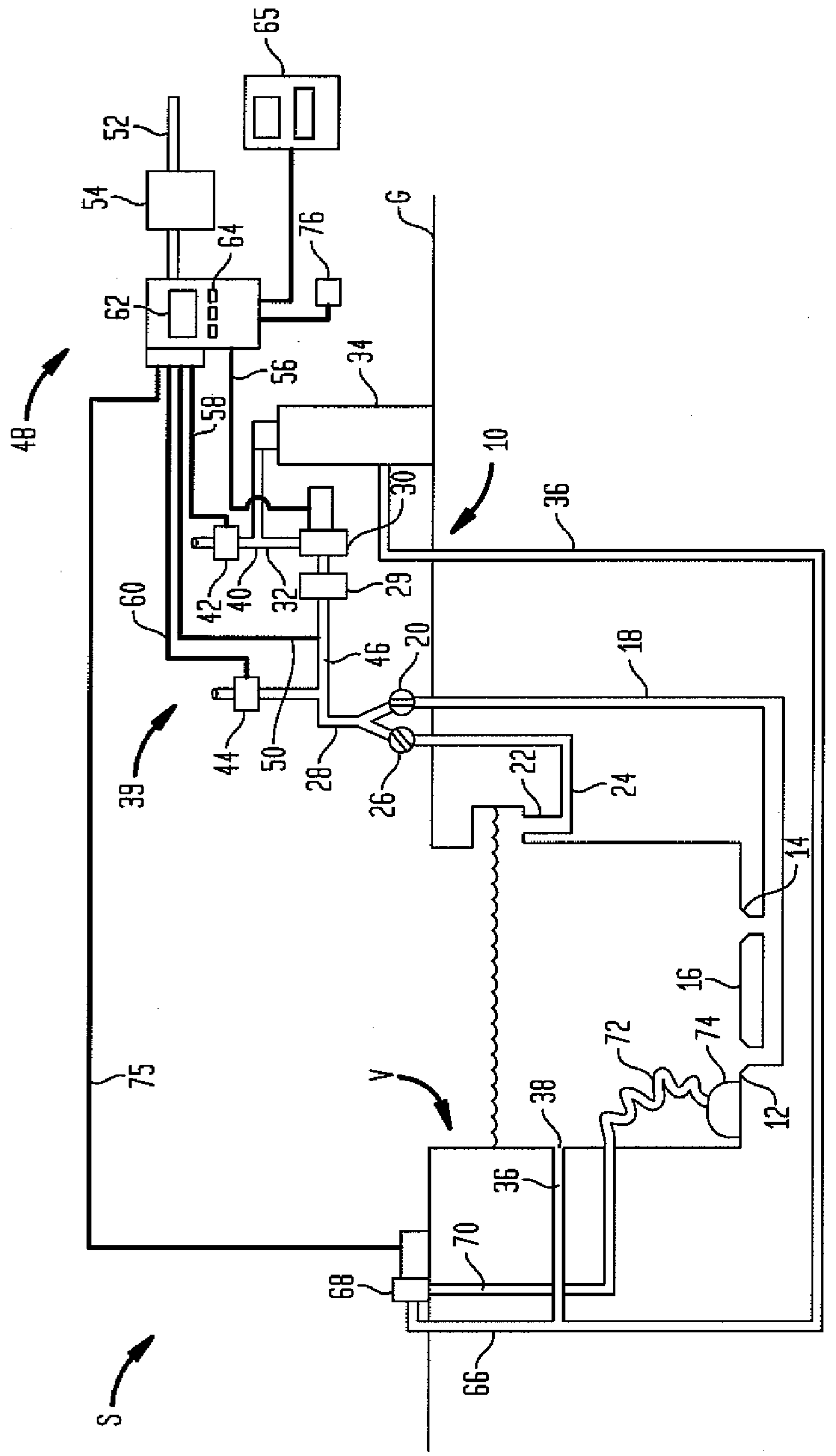
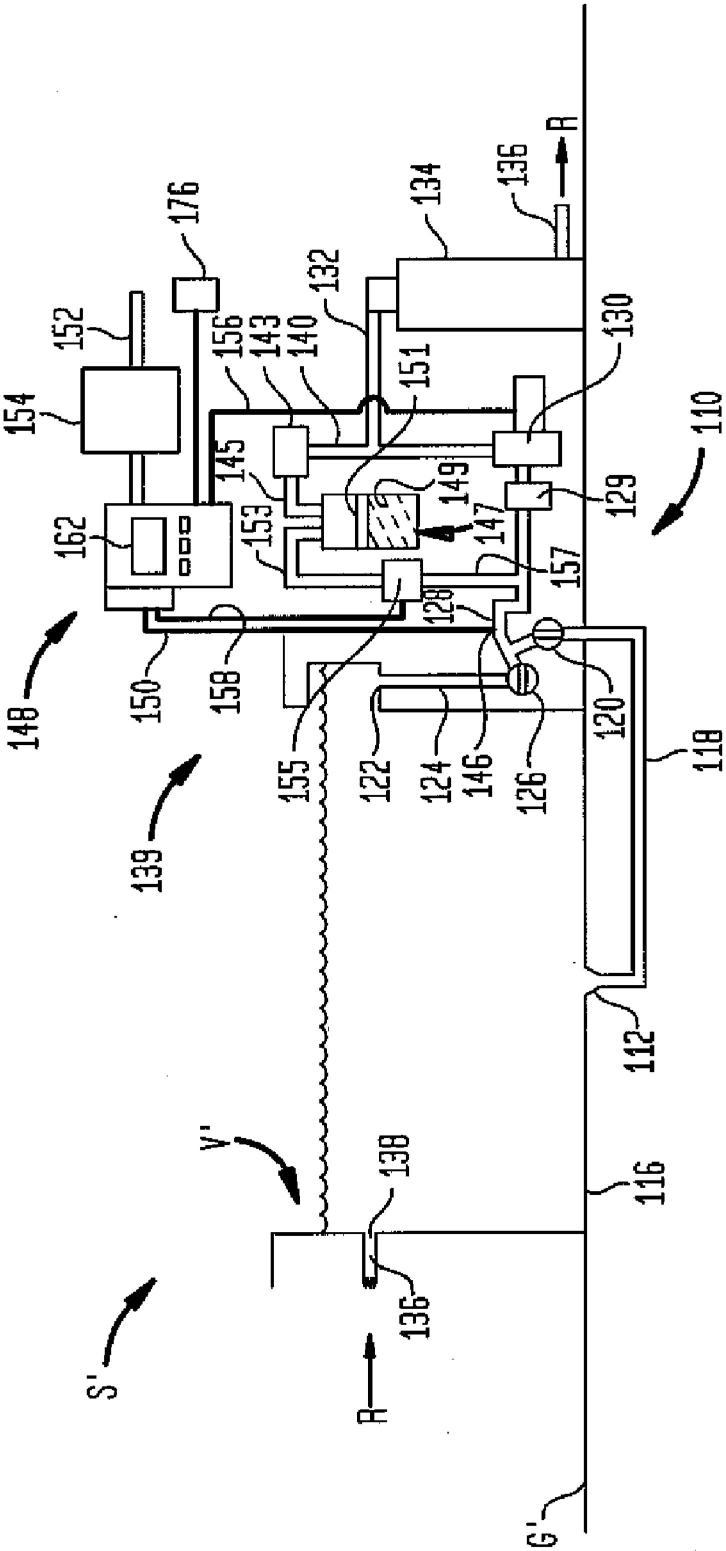

65
52
54
64
62
76
G
48
34
56
58
10
36
30
42
40
32
29
60
20
18
46
44
50
28
26
22
24
39
14
16
72
74
12
V
38
36
75
70
68
66
S

FIG. 2



176
152
154
162
156
143
140
132
134
136
R
151
145
149
153
147
157
129
130
110
128
148
150
158
155
122
124
146
126
120
118
139
112
V'
138
136
116
S'
R
G'

FIG. 4

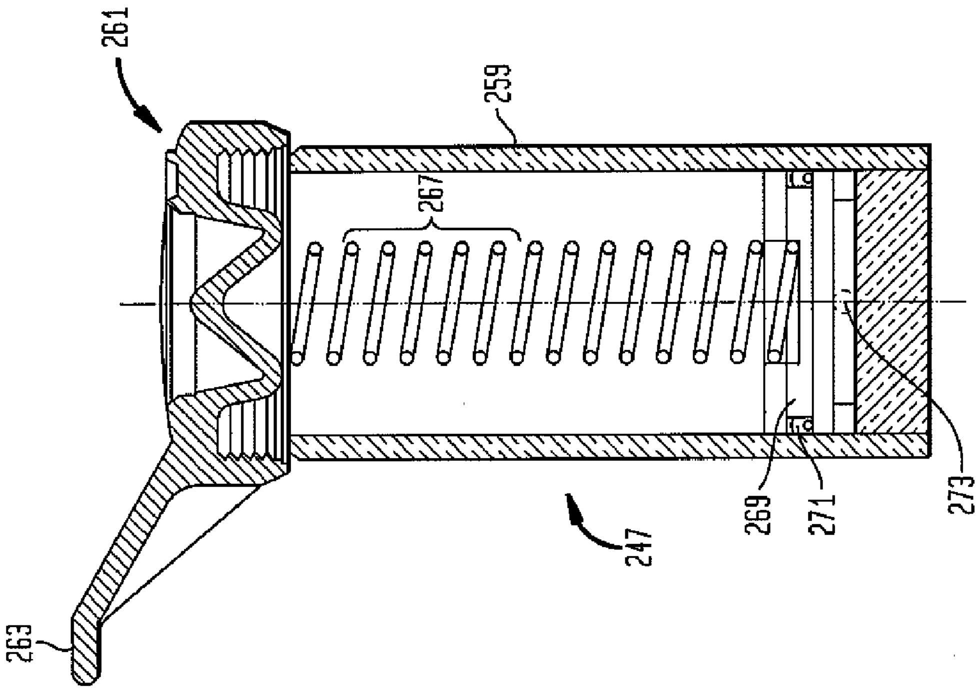


FIG. 3

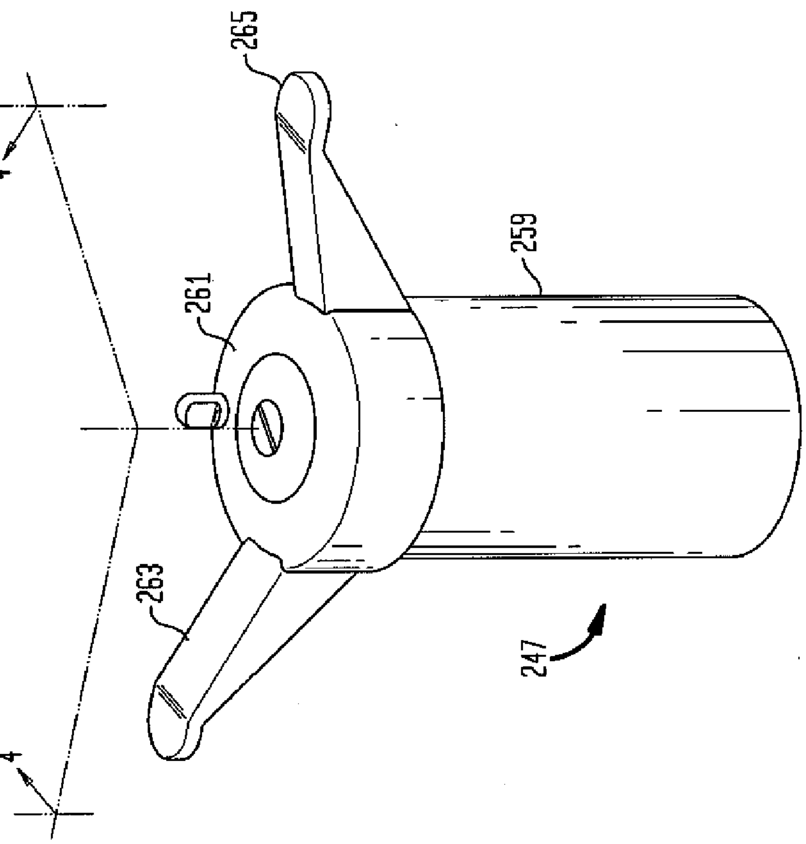


FIG. 5

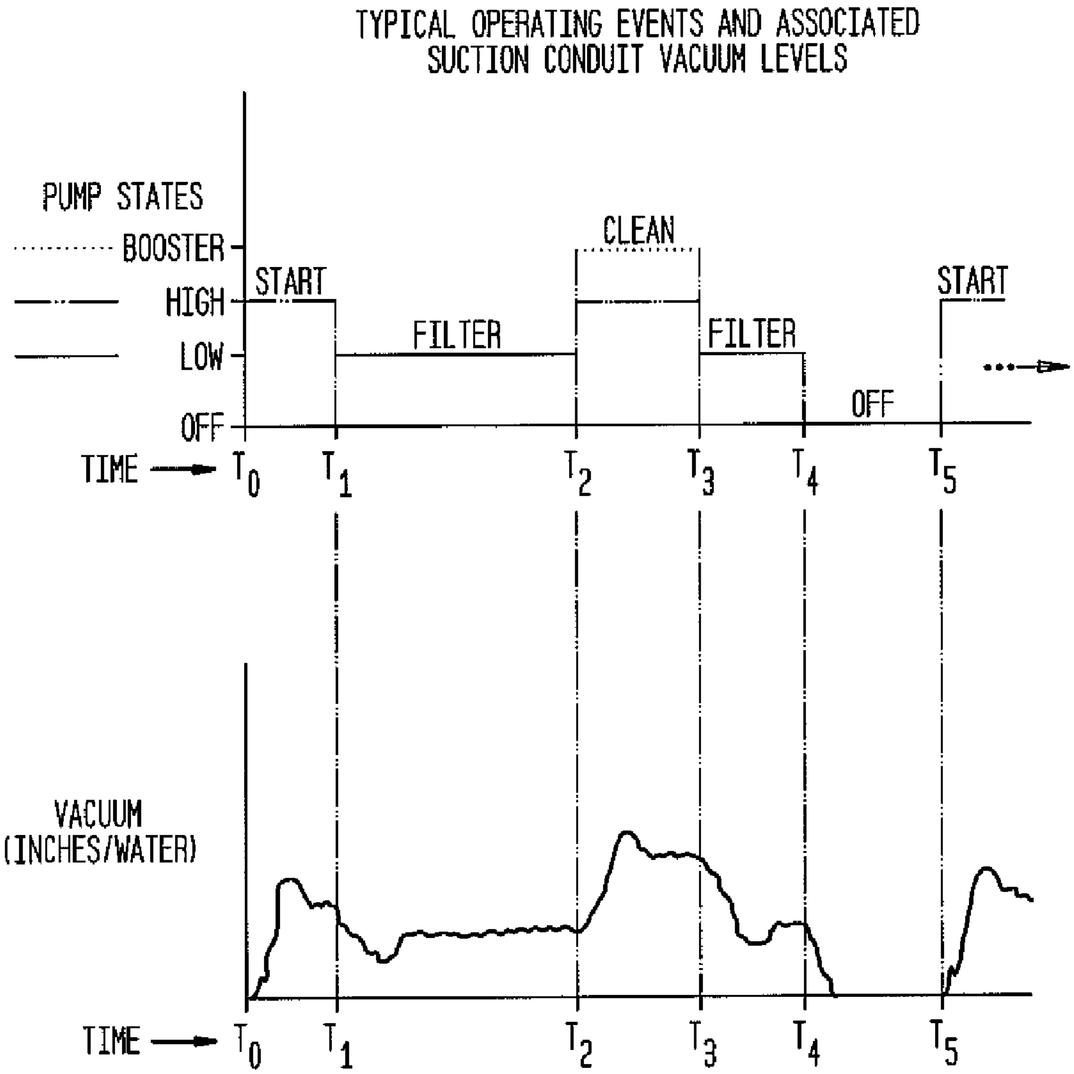

TYPICAL OPERATING EVENTS AND ASSOCIATED
SUCTION CONDUIT VACUUM LEVELS
PUMP STATES
BOOSTER
HIGH
LOW
OFF
START
FILTER
CLEAN
FILTER
OFF
START
TIME
T_0
T_1
T_2
T_3
T_4
T_5
VACUUM
(INCHES/WATER)
TIME
T_0
T_1
T_2
T_3
T_4
T_5

FIG. 6

BASELINE STARTUP AND STABILIZATION FOR PUMP ABOVE WATER LEVEL

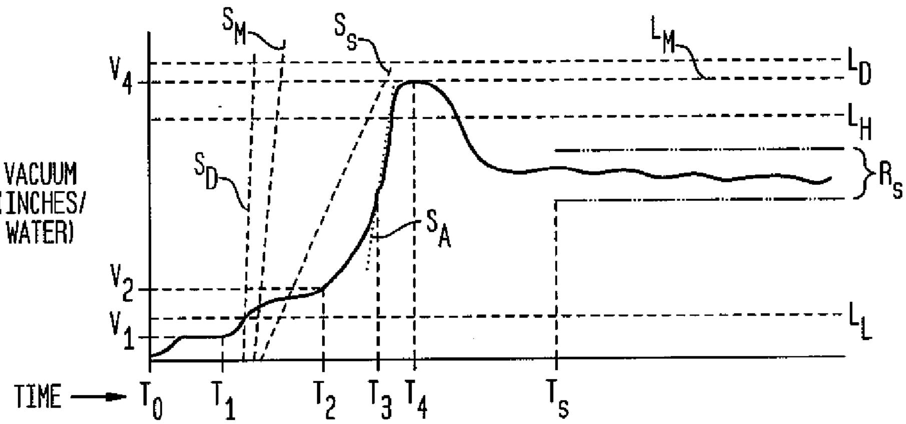


FIG. 7

STARTUP WITH TIMED VACUUM RELEASES

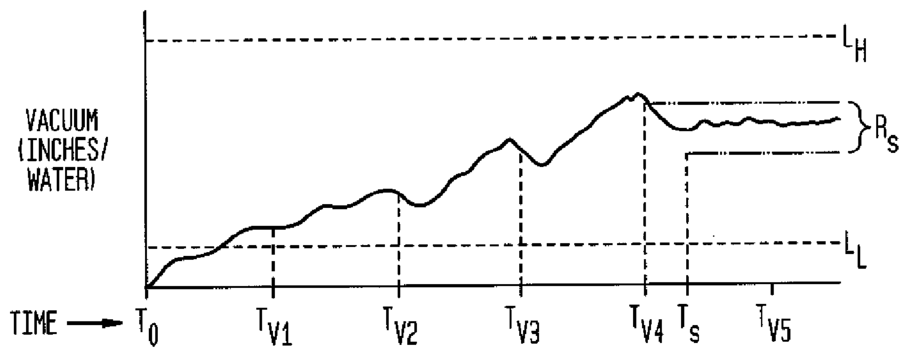


FIG. 8

FILTRATION INTERRUPTED BY ANOMALIES

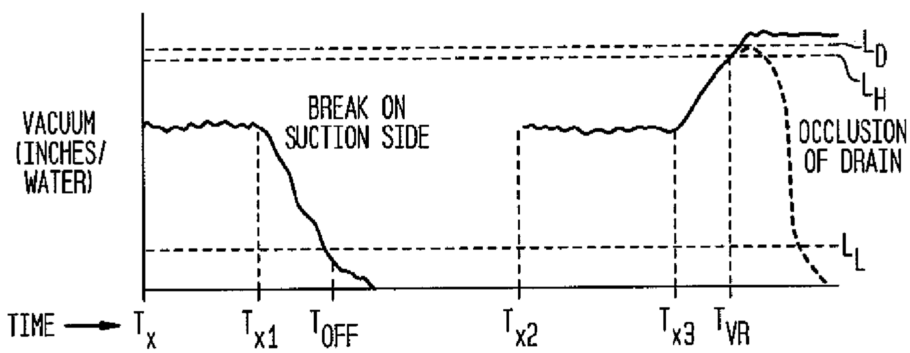
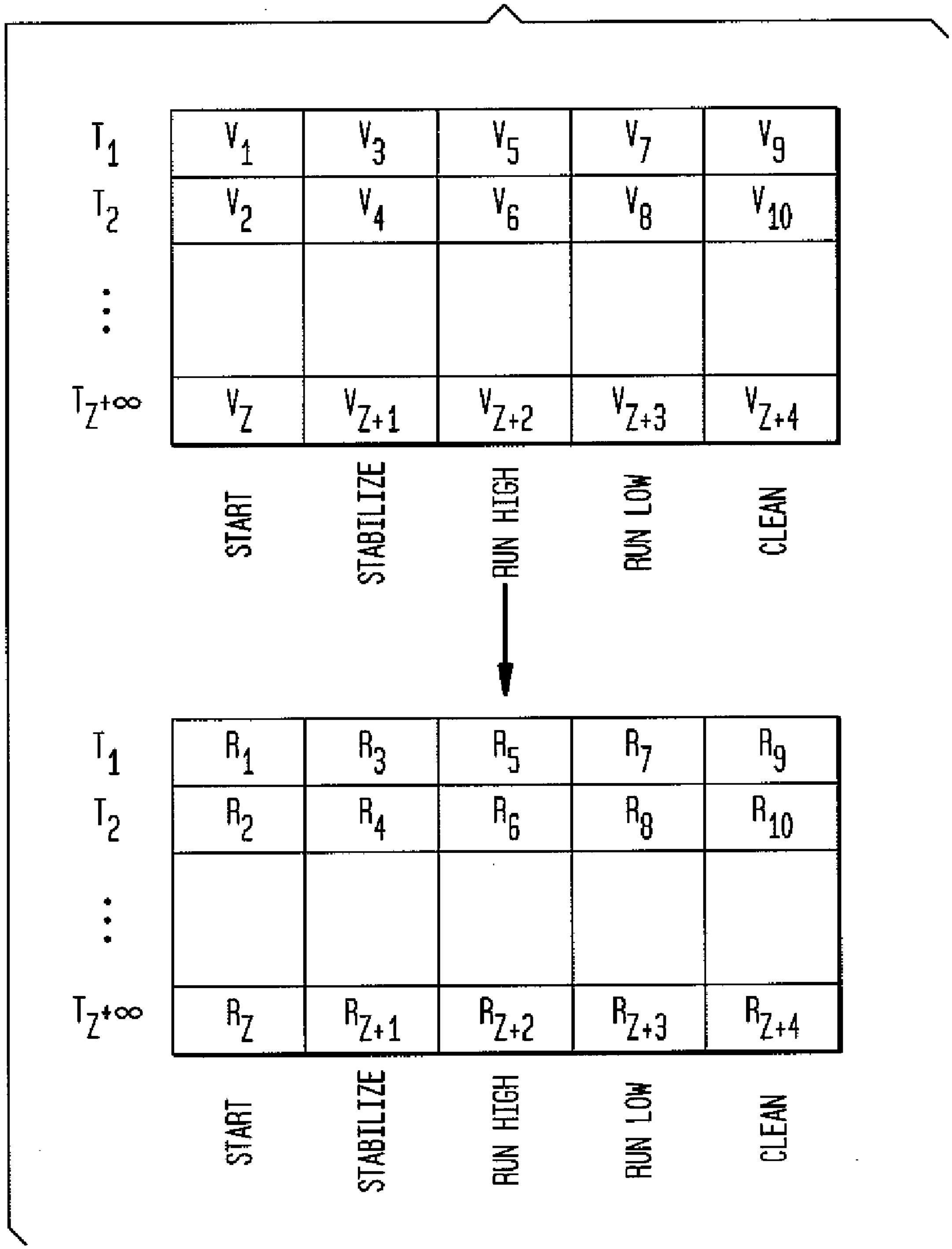
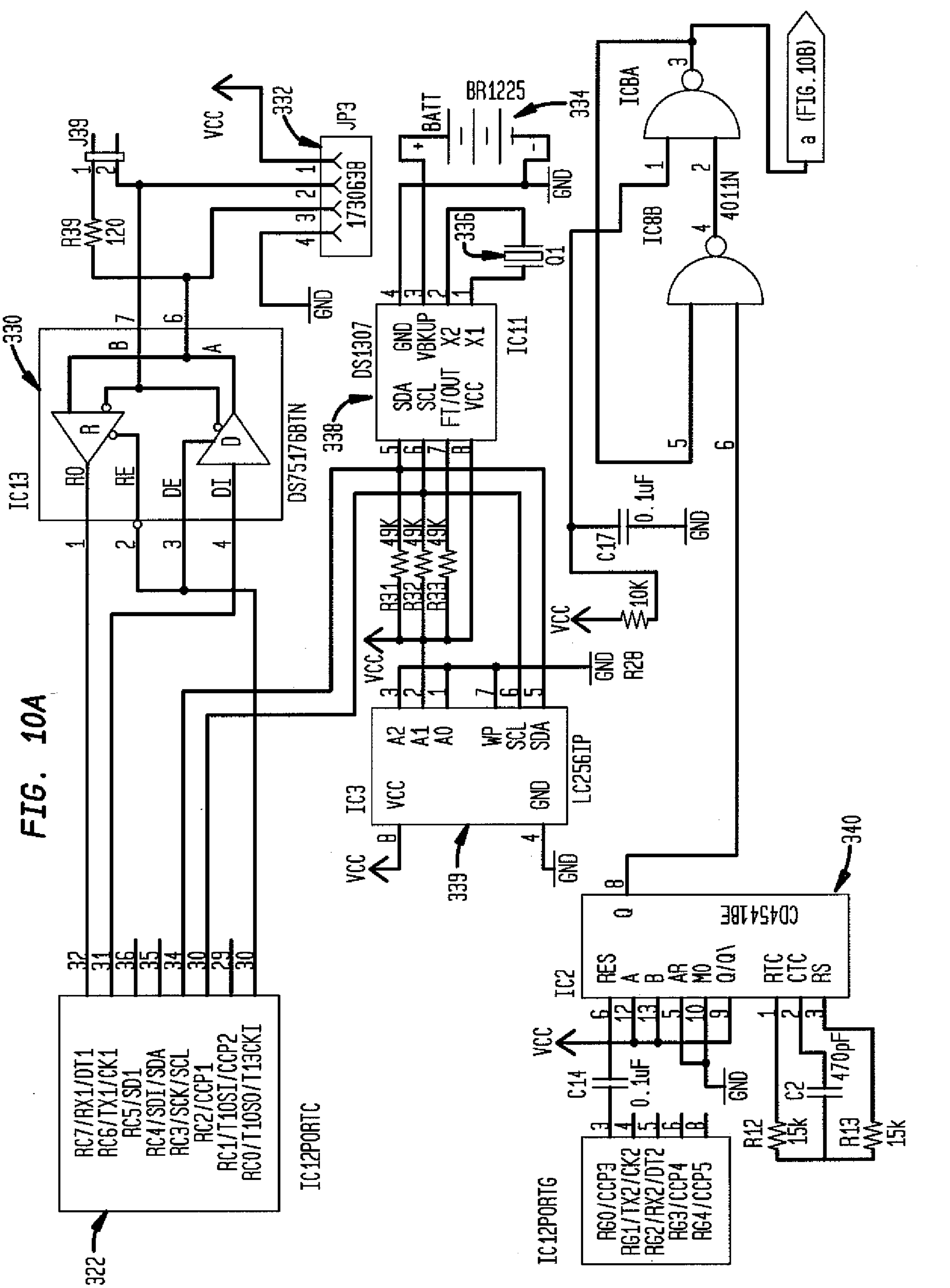


FIG. 9



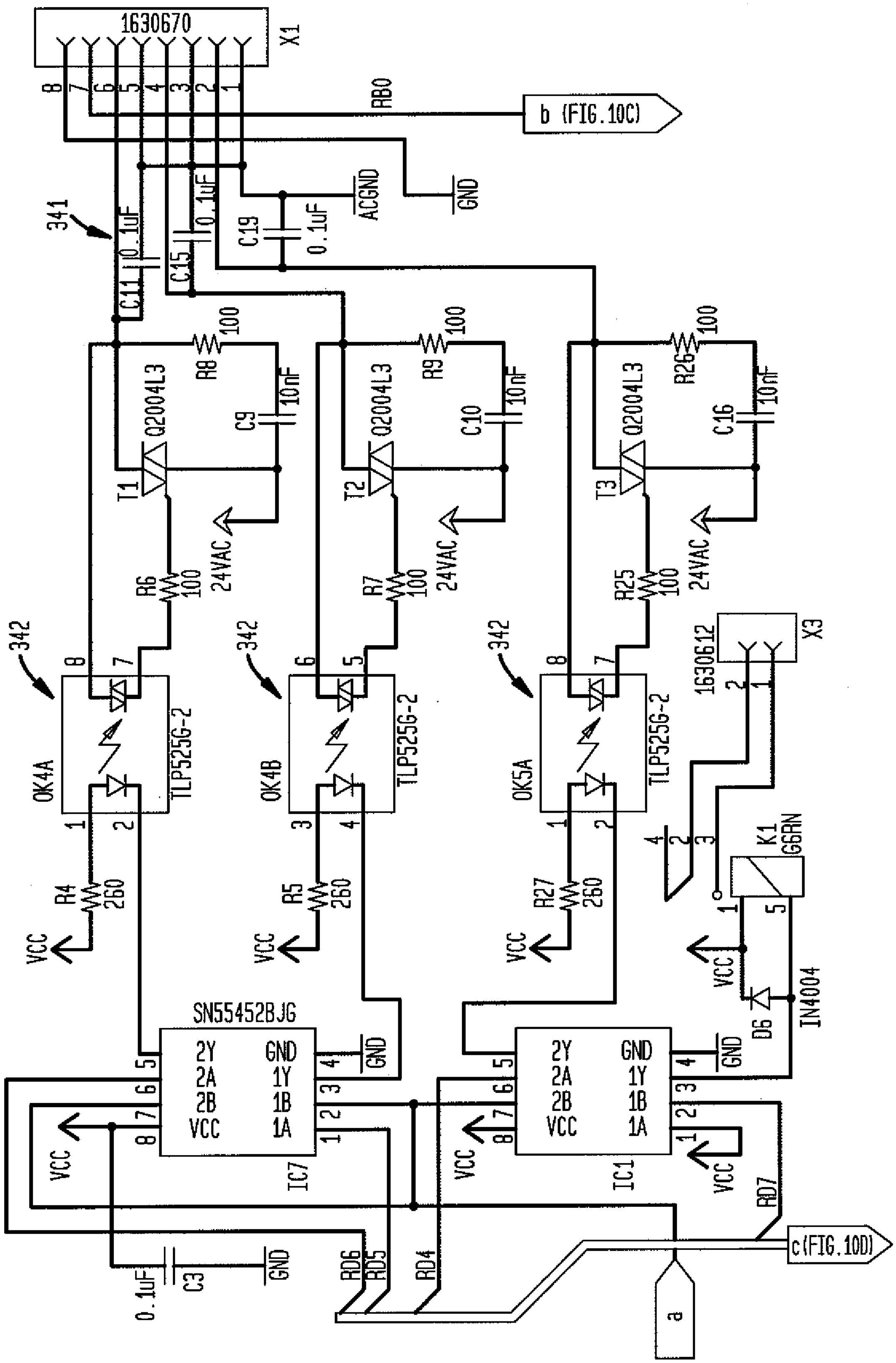
T_1
T_2
$T_{Z+\infty}$
V_1 V_3 V_5 V_7 V_9
V_2 V_4 V_6 V_8 V_{10}
V_Z V_{Z+1} V_{Z+2} V_{Z+3} V_{Z+4}
START
STABILIZE
RUN HIGH
RUN LOW
CLEAN
T_1
T_2
$T_{Z+\infty}$
R_1 R_3 R_5 R_7 R_9
R_2 R_4 R_6 R_8 R_{10}
R_Z R_{Z+1} R_{Z+2} R_{Z+3} R_{Z+4}
START
STABILIZE
RUN HIGH
RUN LOW
CLEAN



IC13
DS75176BTN
330
RO
RE
DE
DI
R
D
B
A
J39
R39
120
VCC
332
JP3
1730638
GND
BR1225
BATT
334
336
Q1
DS1307
338
SDA
SCL
FT/OUT
VCC
GND
VBKUP
X2
X1
IC11
ICBA
IC8B
4011N
a (FIG. 10B)
C17
0.1uF
10K
R31
R32
R33
49K
R28
IC3
LC256IP
A2
A1
A0
WP
339
340
CD4541BE
IC2
RES
AR
MO
Q/Q\
RTC
CTC
RS
C14
C2
470pF
R12
15k
R13
IC12PORTC
RC7/RX1/DT1
RC6/TX1/CK1
RC5/SD1
RC4/SDI/SDA
RC3/SCK/SCL
RC2/CCP1
RC1/T1OSI/CCP2
RC0/T1OSO/T13CKI
322
IC12PORTG
RG0/CCP3
RG1/TX2/CK2
RG2/RX2/DT2
RG3/CCP4
RG4/CCP5

FIG. 10A

FIG. 10B



1630670
X1
RB0
b (FIG.10C)
ACGND
GND
341
C11
0.1uF
C15
0.1uF
C19
0.1uF
R8
R9
R26
100
Q2004L3
C9
C10
C16
10nF
T1
T2
T3
24VAC
R6
R7
R25
342
OK4A
OK4B
OK5A
TLP525G-2
1630612
X3
K1
G6RN
R4
R5
R27
260
VCC
SN55452BJG
2Y
2A
2B
1Y
1B
1A
IC7
IC1
D6
IN4004
C3
RD6
RD5
RD4
RD7
c (FIG.10D)
a

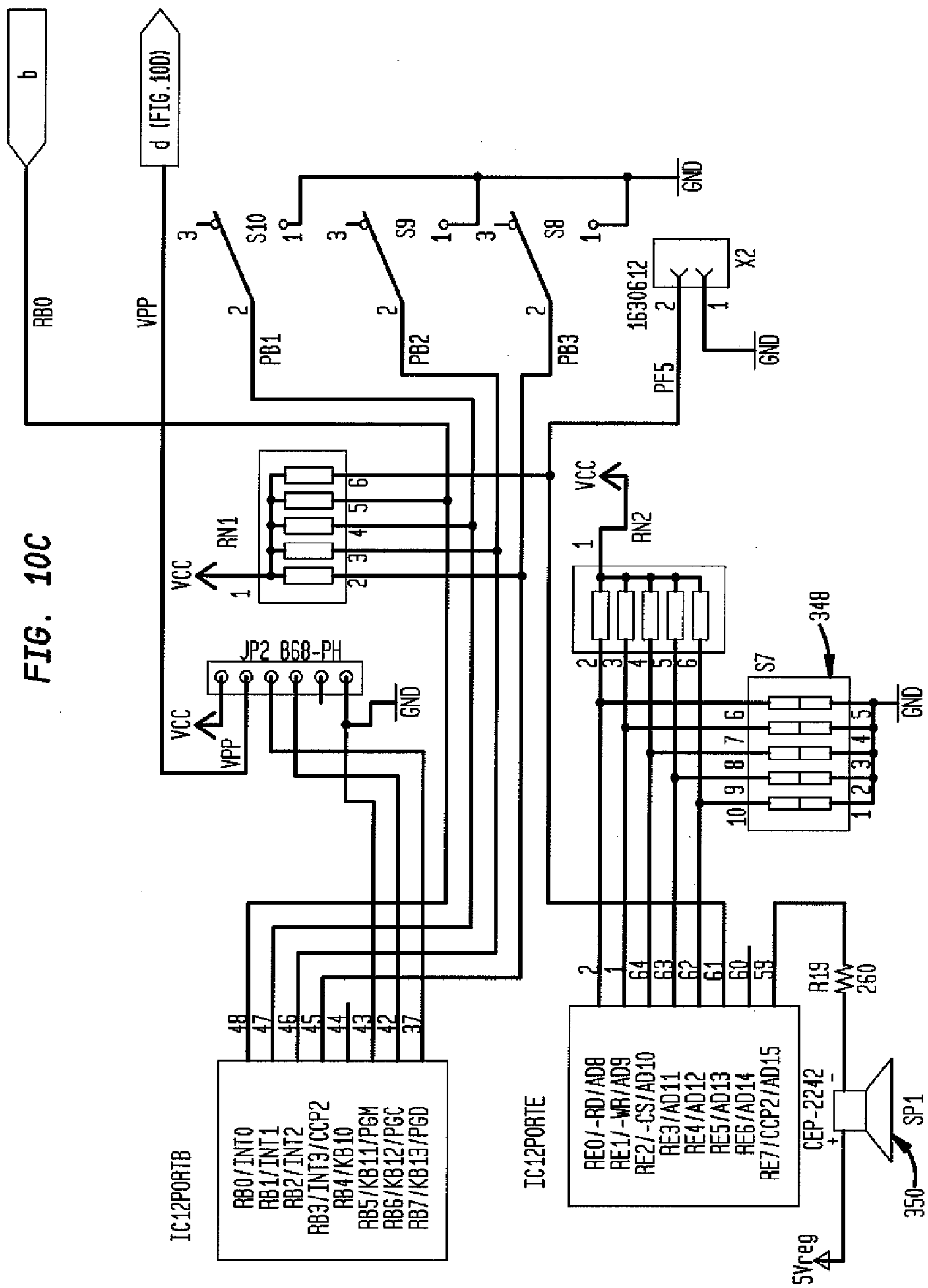

b
d (FIG.10D)
RB0
VPP
S10
S9
S8
PB1
PB2
PB3
GND
X2
1630612
PF5
RN1
RN2
VCC
JP2 B68-PH
S7
348
IC12PORTB
RB0/INT0
RB1/INT1
RB2/INT2
RB3/INT3/CCP2
RB4/KB10
RB5/KB11/PGM
RB6/KB12/PGC
RB7/KB13/PGD
IC12PORTE
RE0/-RD/AD8
RE1/-WR/AD9
RE2/-CS/AD10
RE3/AD11
RE4/AD12
RE5/AD13
RE6/AD14
RE7/CCP2/AD15
R19
260
CEP-2242
SP1
350
5Vreg

FIG. 10C

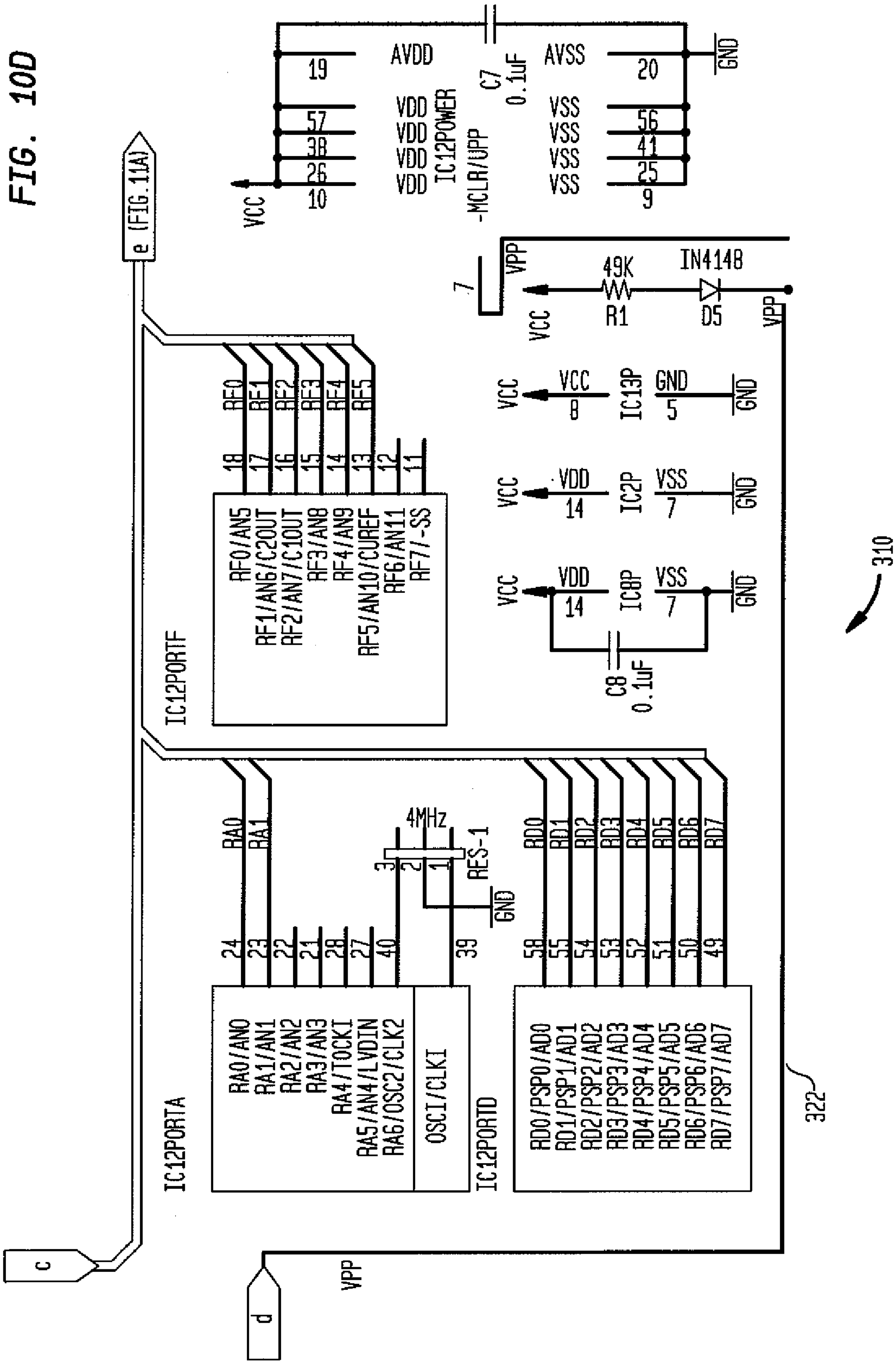

e (FIG. 11A)
IC12POWER
AVDD
AVSS
VDD
VSS
-MCLR/UPP
C7
0.1uF
GND
VCC
VPP
49K
R1
IN4148
D5
IC13P
IC2P
IC8P
C8
0.1uF
IC12PORTF
RF0/AN5
RF1/AN6/C2OUT
RF2/AN7/C1OUT
RF3/AN8
RF4/AN9
RF5/AN10/CUREF
RF6/AN11
RF7/-SS
IC12PORTA
RA0/AN0
RA1/AN1
RA2/AN2
RA3/AN3
RA4/TOCKI
RA5/AN4/LVDIN
RA6/OSC2/CLK2
OSCI/CLKI
4MHz
RES-1
IC12PORTD
RD0/PSP0/AD0
RD1/PSP1/AD1
RD2/PSP2/AD2
RD3/PSP3/AD3
RD4/PSP4/AD4
RD5/PSP5/AD5
RD6/PSP6/AD6
RD7/PSP7/AD7
310
322
c
d

FIG. 10D

FIG. 11A

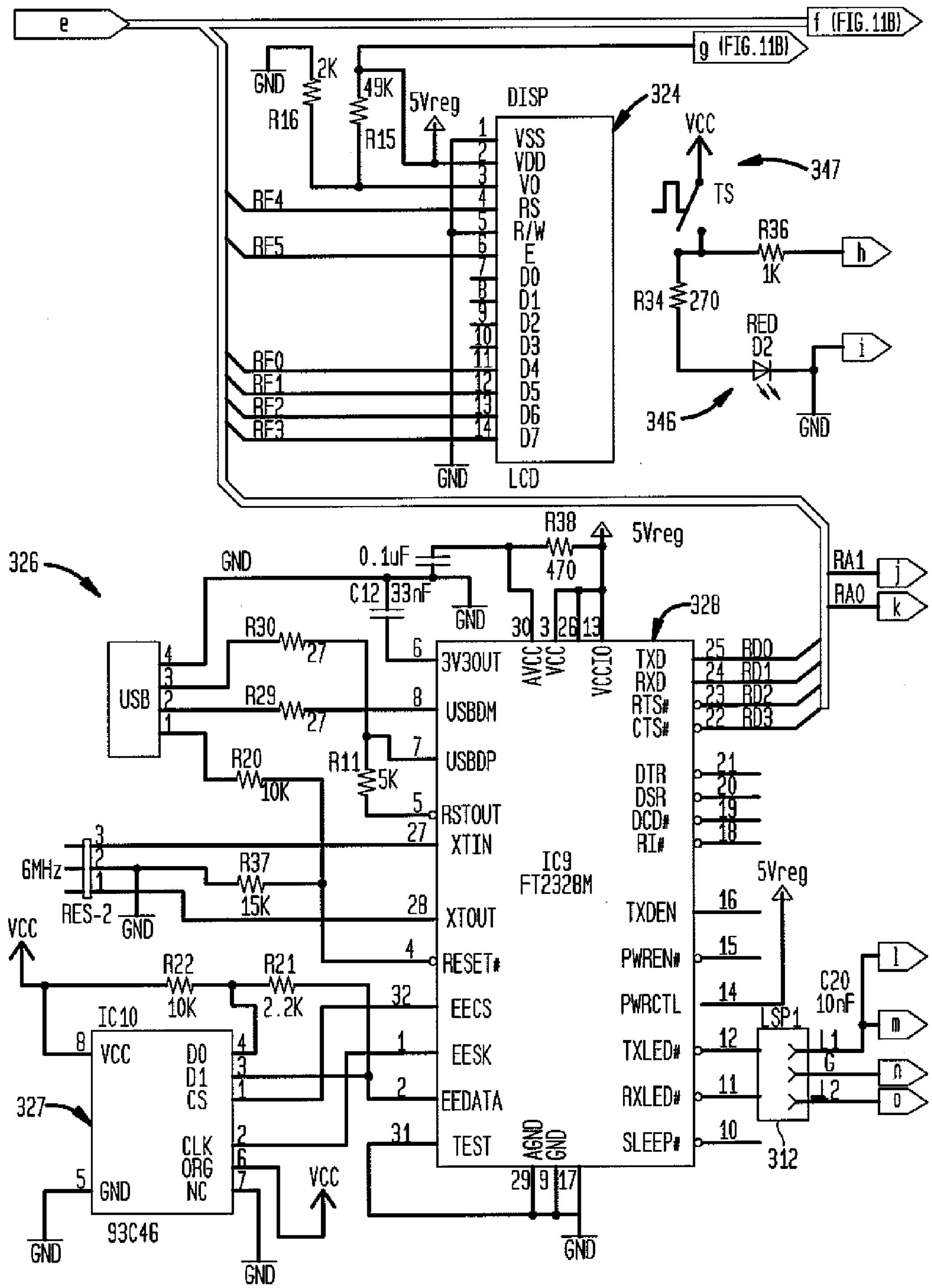
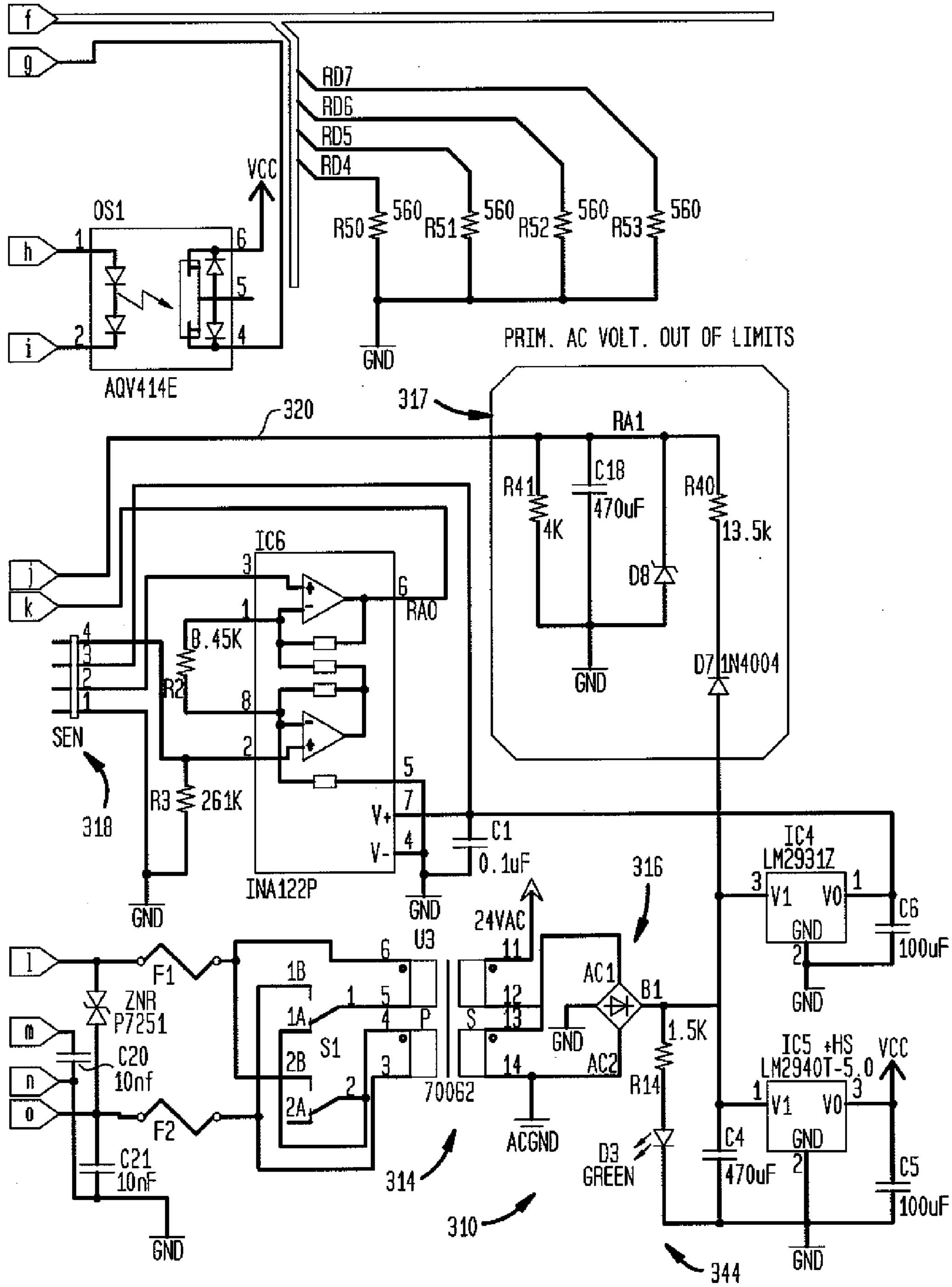

e
f (FIG.11B)
g (FIG.11B)
GND
2K
R16
49K
R15
5Vreg
DISP
324
VSS
VDD
VO
RS
R/W
E
D0
D1
D2
D3
D4
D5
D6
D7
LCD
RF4
RF5
RF0
RF1
RF2
RF3
VCC
347
TS
R36
1K
h
R34
270
RED
D2
i
346
R38
470
5Vreg
326
0.1uF
C12
33nF
328
USB
R30
27
R29
27
R20
10K
R11
5K
3V3OUT
USBDM
USBDP
RSTOUT
XTIN
XTOUT
RESET#
EECS
EESK
EEDATA
TEST
AVCC
VCC
VCCIO
AGND
TXD
RXD
RTS#
CTS#
RD0
RD1
RD2
RD3
RA1
RA0
j
k
DTR
DSR
DCD#
RI#
IC9
FT232BM
TXDEN
PWREN#
PWRCTL
TXLED#
RXLED#
SLEEP#
6MHz
RES-2
R37
15K
R22
10K
R21
2.2K
IC10
327
D0
D1
CS
CLK
ORG
NC
93C46
C20
10nF
LSP1
L1
G
L2
l
m
n
o
312

FIG. 11B



f
g
RD7
RD6
RD5
RD4
VCC
OS1
h
i
AQV414E
R50 560
R51 560
R52 560
R53 560
GND
PRIM. AC VOLT. OUT OF LIMITS
320
317
RA1
R41 4K
C18 470uF
R40 13.5k
D8
D7 1N4004
GND
j
k
IC6
RA0
8.45K
R2
SEN
318
R3 261K
V+
V-
INA122P
C1 0.1uF
GND
316
IC4 LM2931Z
V1 V0
C6 100uF
24VAC
U3
l
m
n
o
F1
F2
ZNR P7251
C20 10nf
C21 10nF
1B
1A
S1
2B
2A
P
S
70062
AC1
B1
AC2
1.5K
R14
ACGND
D3 GREEN
C4 470uF
IC5 +HS LM2940T-5.0
VCC
C5 100uF
314
310
344

FIG. 12

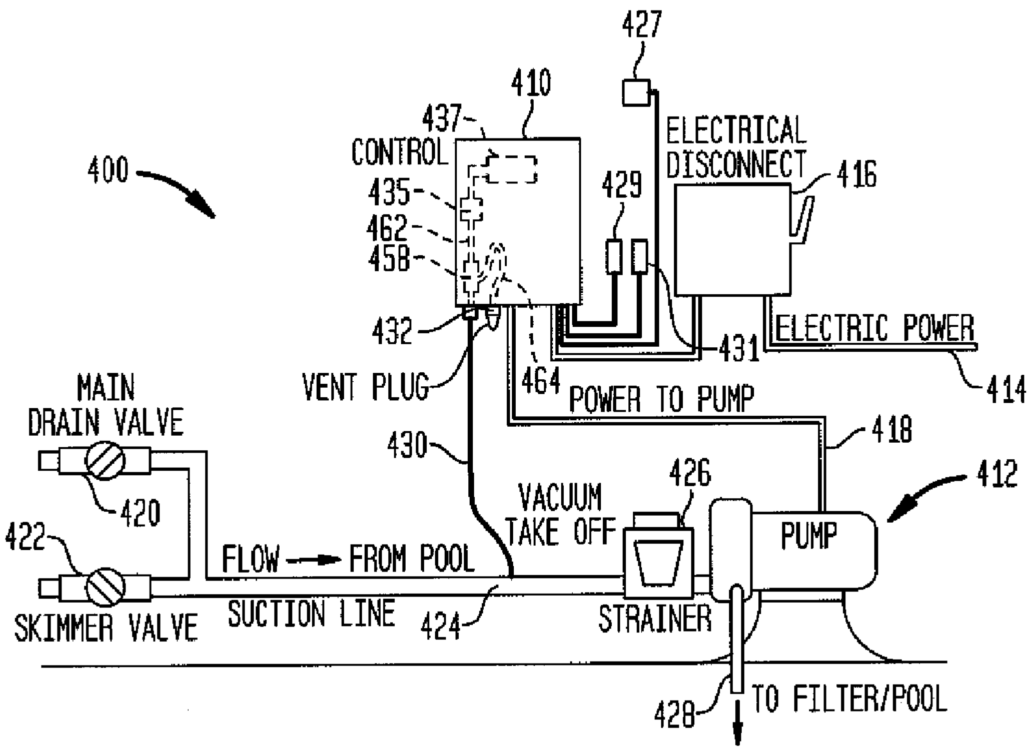

427
410
437
CONTROL
435
462
458
432
VENT PLUG
464
400
ELECTRICAL
DISCONNECT
416
429
431
ELECTRIC POWER
414
POWER TO PUMP
418
MAIN
DRAIN VALVE
420
422
SKIMMER VALVE
430
FLOW FROM POOL
SUCTION LINE
424
VACUUM
TAKE OFF
426
STRAINER
PUMP
412
428
TO FILTER/POOL

FIG. 13

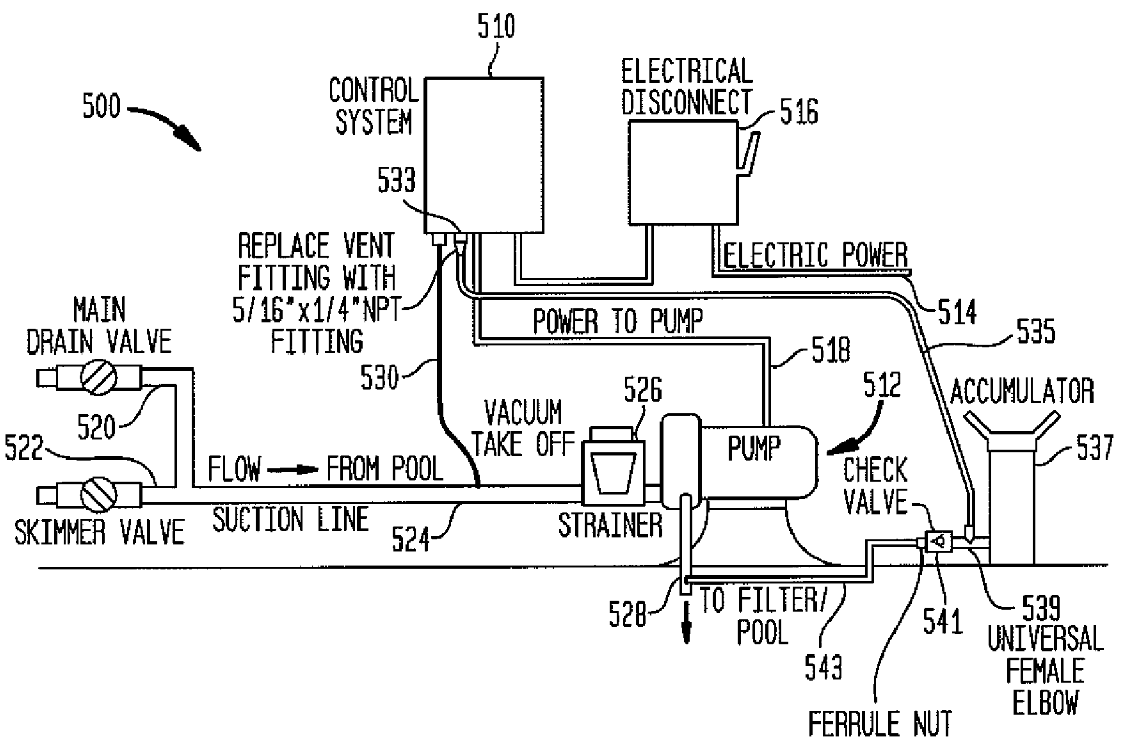

510
CONTROL SYSTEM
ELECTRICAL DISCONNECT
516
500
533
REPLACE VENT FITTING WITH 5/16"x1/4"NPT FITTING
ELECTRIC POWER
514
535
POWER TO PUMP
MAIN DRAIN VALVE
518
530
512
ACCUMULATOR
526
VACUUM TAKE OFF
520
537
522
PUMP
FLOW FROM POOL
CHECK VALVE
SKIMMER VALVE
SUCTION LINE
STRAINER
524
528
TO FILTER/ POOL
541
539
UNIVERSAL FEMALE ELBOW
543
FERRULE NUT

FIG. 14

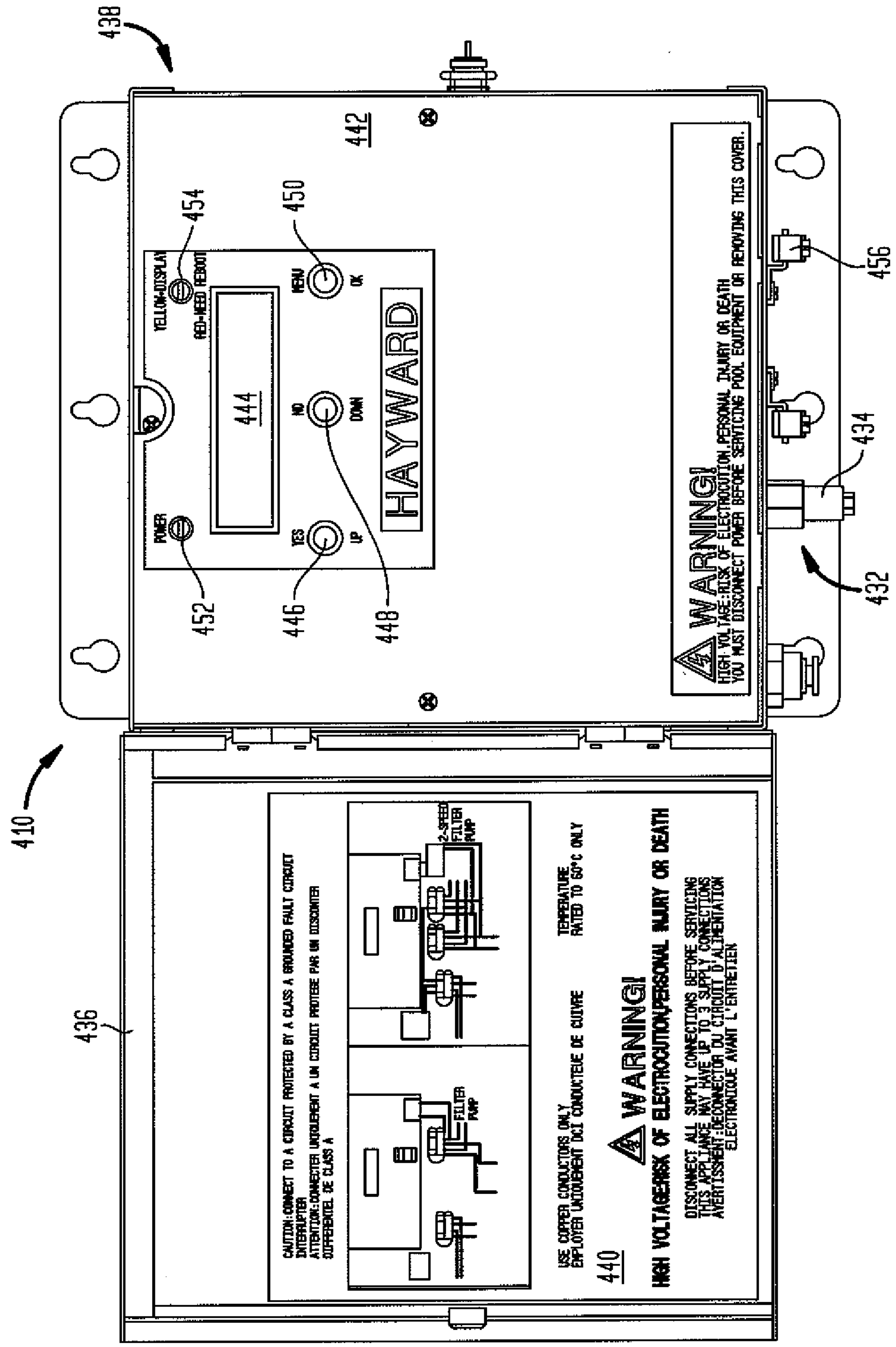

438
442
454
450
444
456
434
432
452
446
448
410
436
440
HAYWARD
WARNING!
WARNING!

FIG. 15

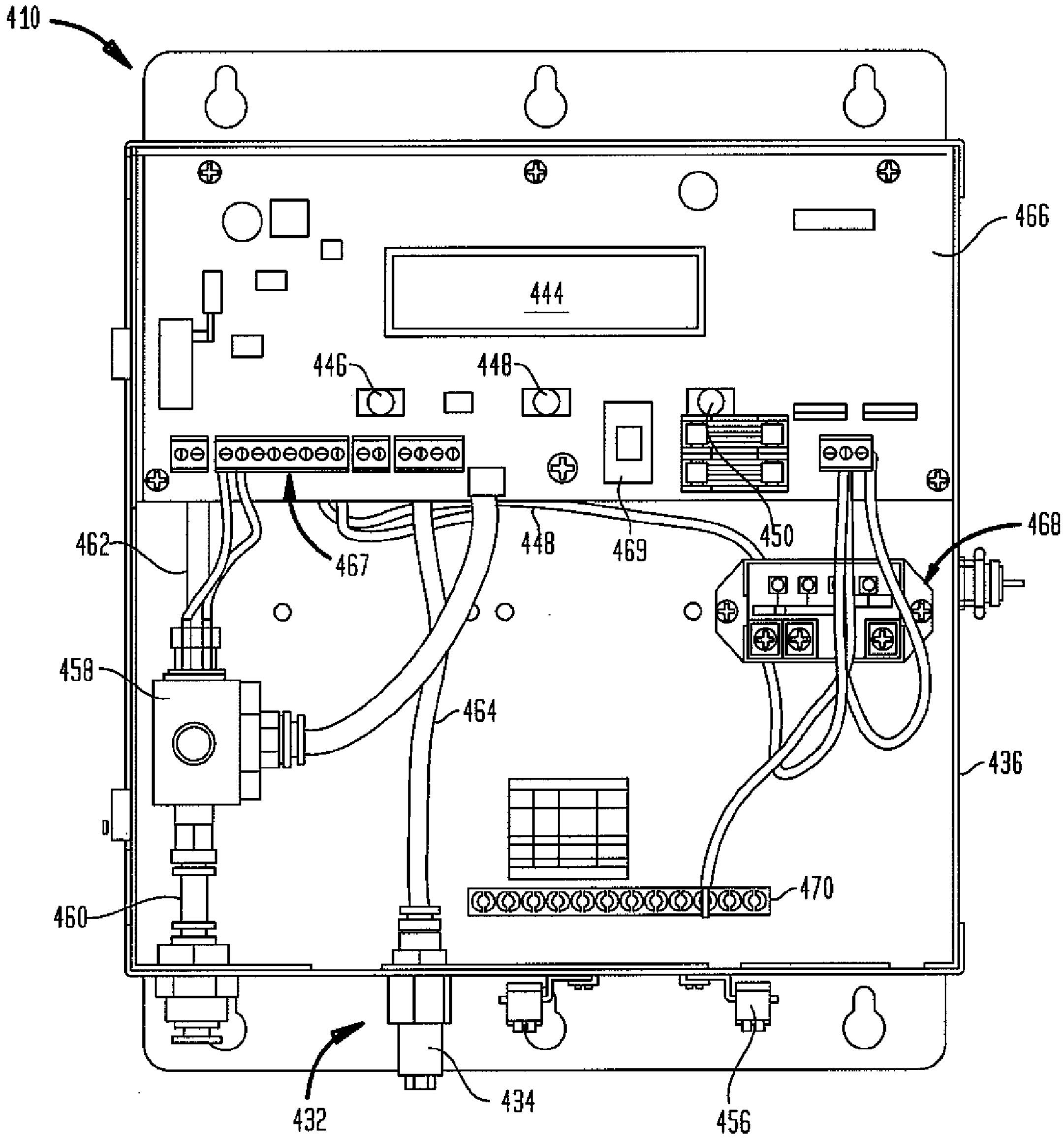
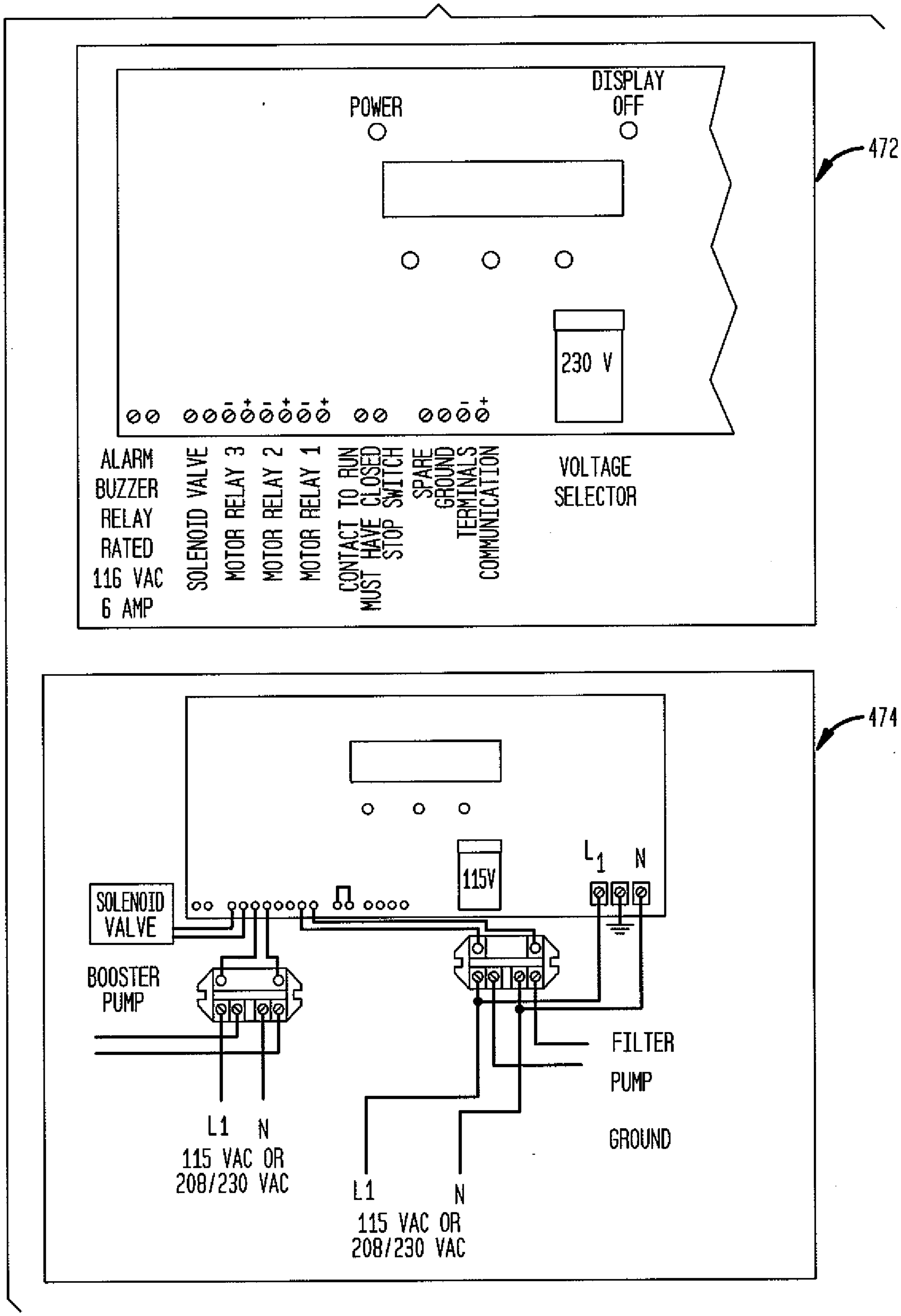

410
466
444
446
448
462
467
448
469
450
468
458
464
436
460
470
432
434
456

FIG. 16A



POWER
DISPLAY OFF
472
230 V
ALARM BUZZER RELAY RATED 116 VAC 6 AMP
SOLENOID VALVE
MOTOR RELAY 3
MOTOR RELAY 2
MOTOR RELAY 1
CONTACT TO RUN MUST HAVE CLOSED STOP SWITCH
SPARE GROUND TERMINALS COMMUNICATION
VOLTAGE SELECTOR
474
115V
L1 N
SOLENOID VALVE
BOOSTER PUMP
L1 N
115 VAC OR 208/230 VAC
FILTER PUMP
GROUND
L1 N
115 VAC OR 208/230 VAC

FIG. 16B

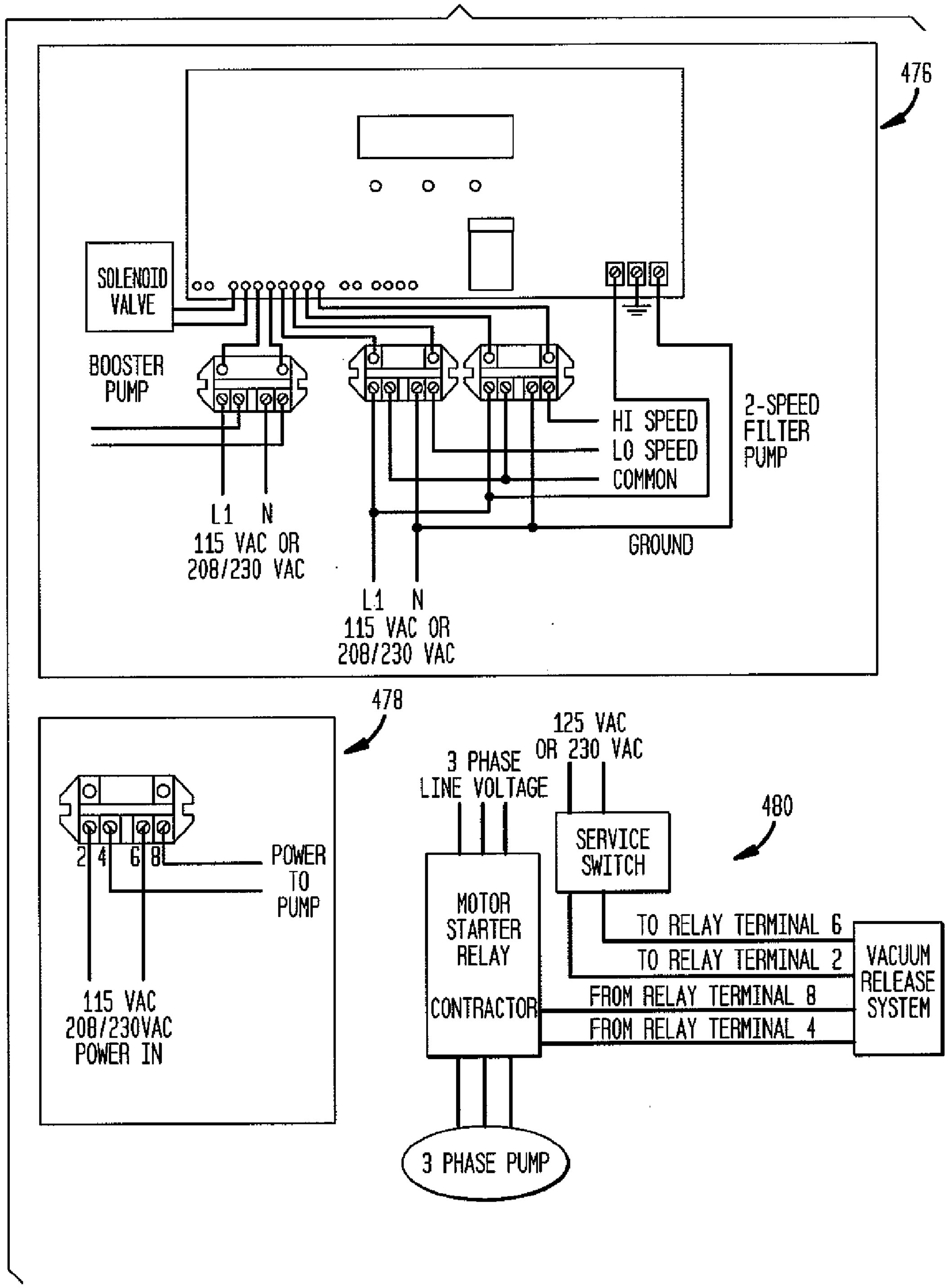

476
SOLENOID VALVE
BOOSTER PUMP
HI SPEED
LO SPEED
COMMON
2-SPEED FILTER PUMP
L1 N
115 VAC OR 208/230 VAC
GROUND
L1 N
115 VAC OR 208/230 VAC
478
2 4 6 8
POWER TO PUMP
115 VAC 208/230VAC POWER IN
125 VAC OR 230 VAC
3 PHASE LINE VOLTAGE
480
SERVICE SWITCH
MOTOR STARTER RELAY CONTRACTOR
TO RELAY TERMINAL 6
TO RELAY TERMINAL 2
FROM RELAY TERMINAL 8
FROM RELAY TERMINAL 4
VACUUM RELEASE SYSTEM
3 PHASE PUMP

FIG. 17

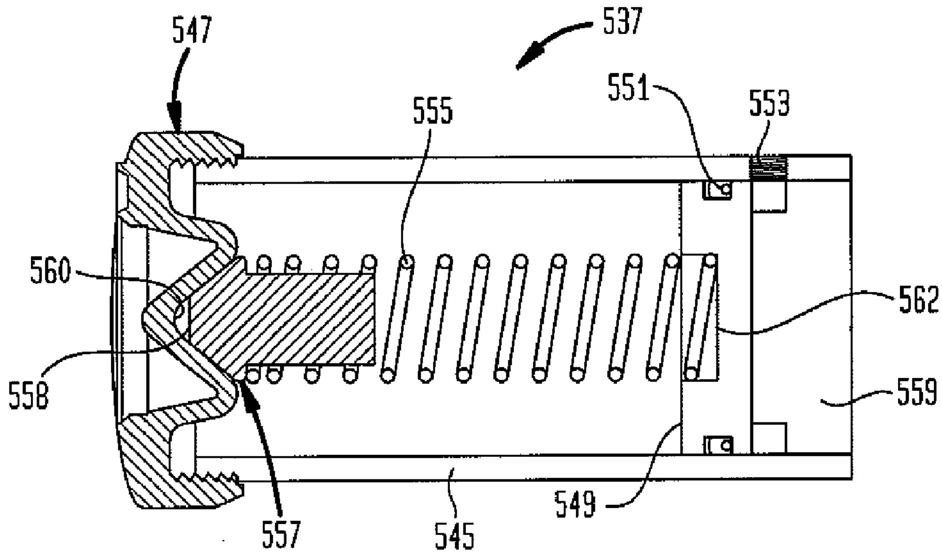

537
547
555
551
553
560
562
558
559
557
545
549

FIG. 18

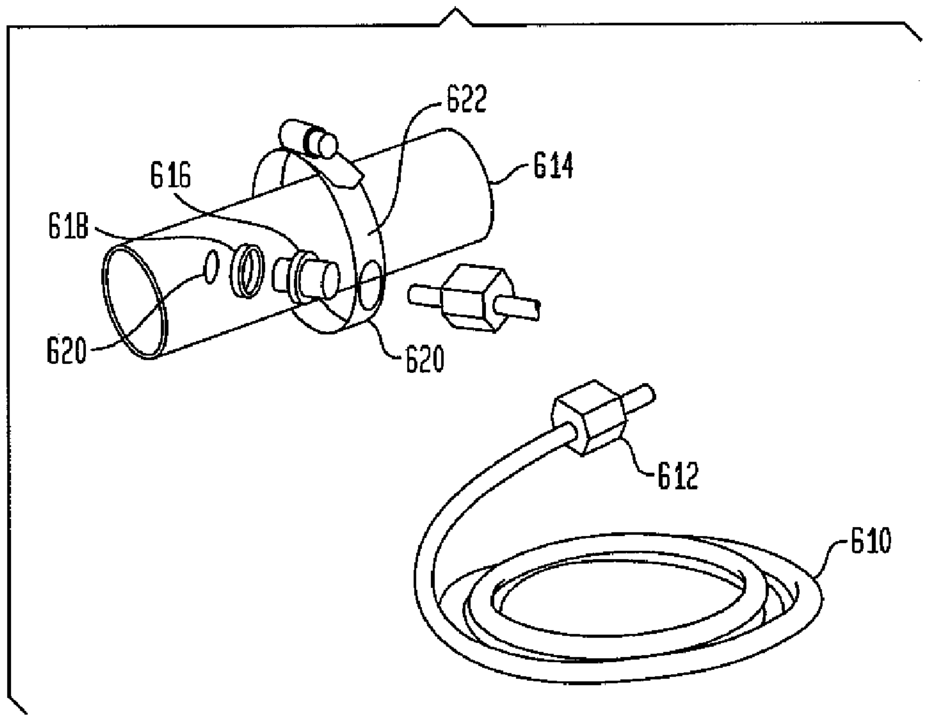
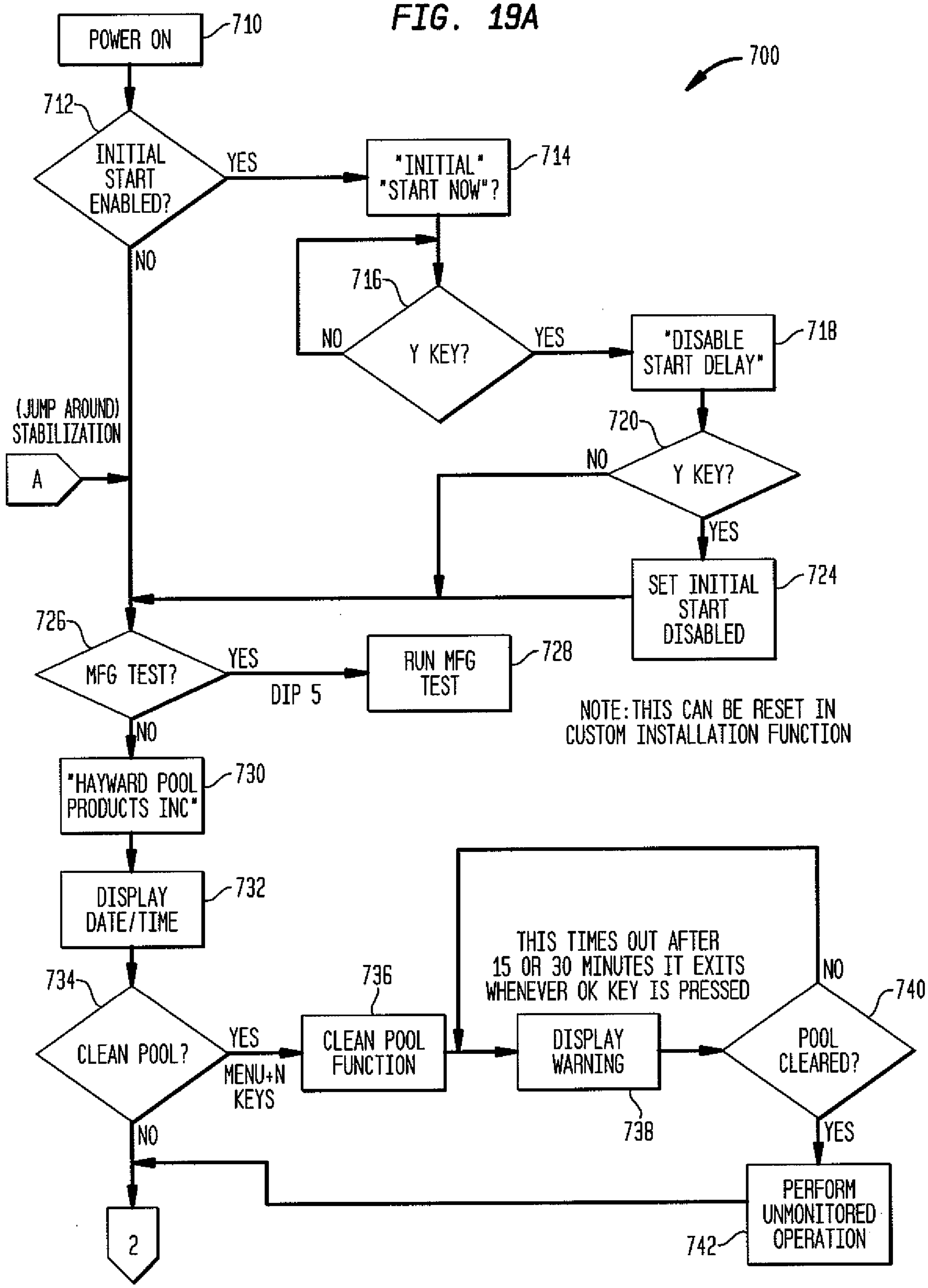

622
616
614
618
620
620
612
610

FIG. 19A



700
POWER ON
710
712
INITIAL START ENABLED?
YES
NO
"INITIAL" "START NOW"?
714
716
Y KEY?
NO
YES
"DISABLE START DELAY"
718
720
Y KEY?
NO
YES
SET INITIAL START DISABLED
724
(JUMP AROUND) STABILIZATION
A
726
MFG TEST?
YES
DIP 5
RUN MFG TEST
728
NO
NOTE: THIS CAN BE RESET IN CUSTOM INSTALLATION FUNCTION
"HAYWARD POOL PRODUCTS INC"
730
DISPLAY DATE/TIME
732
734
CLEAN POOL?
YES
MENU+N KEYS
CLEAN POOL FUNCTION
736
THIS TIMES OUT AFTER 15 OR 30 MINUTES IT EXITS WHENEVER OK KEY IS PRESSED
DISPLAY WARNING
738
POOL CLEARED?
740
NO
YES
NO
PERFORM UNMONITORED OPERATION
742
2

FIG. 19B

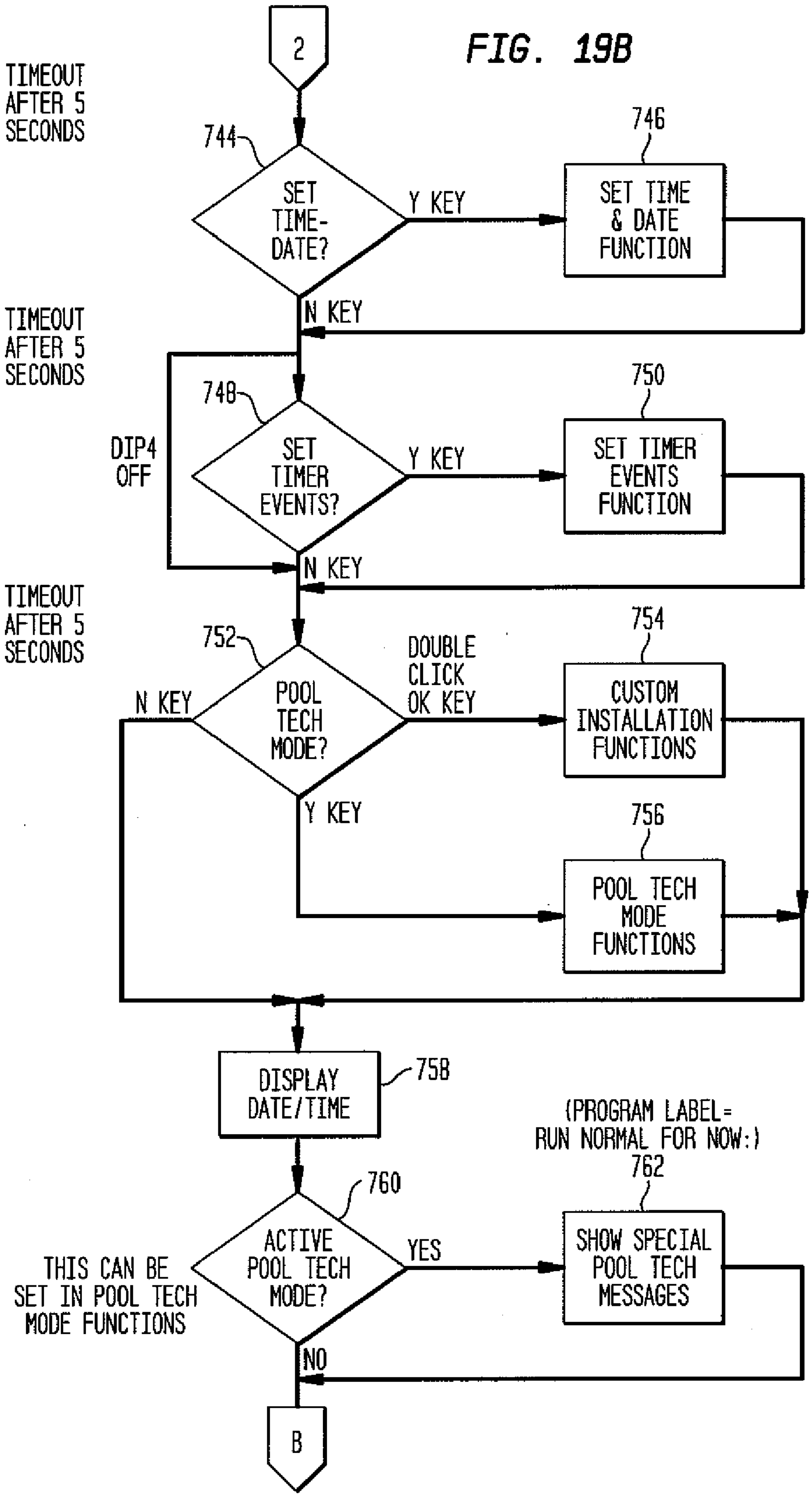
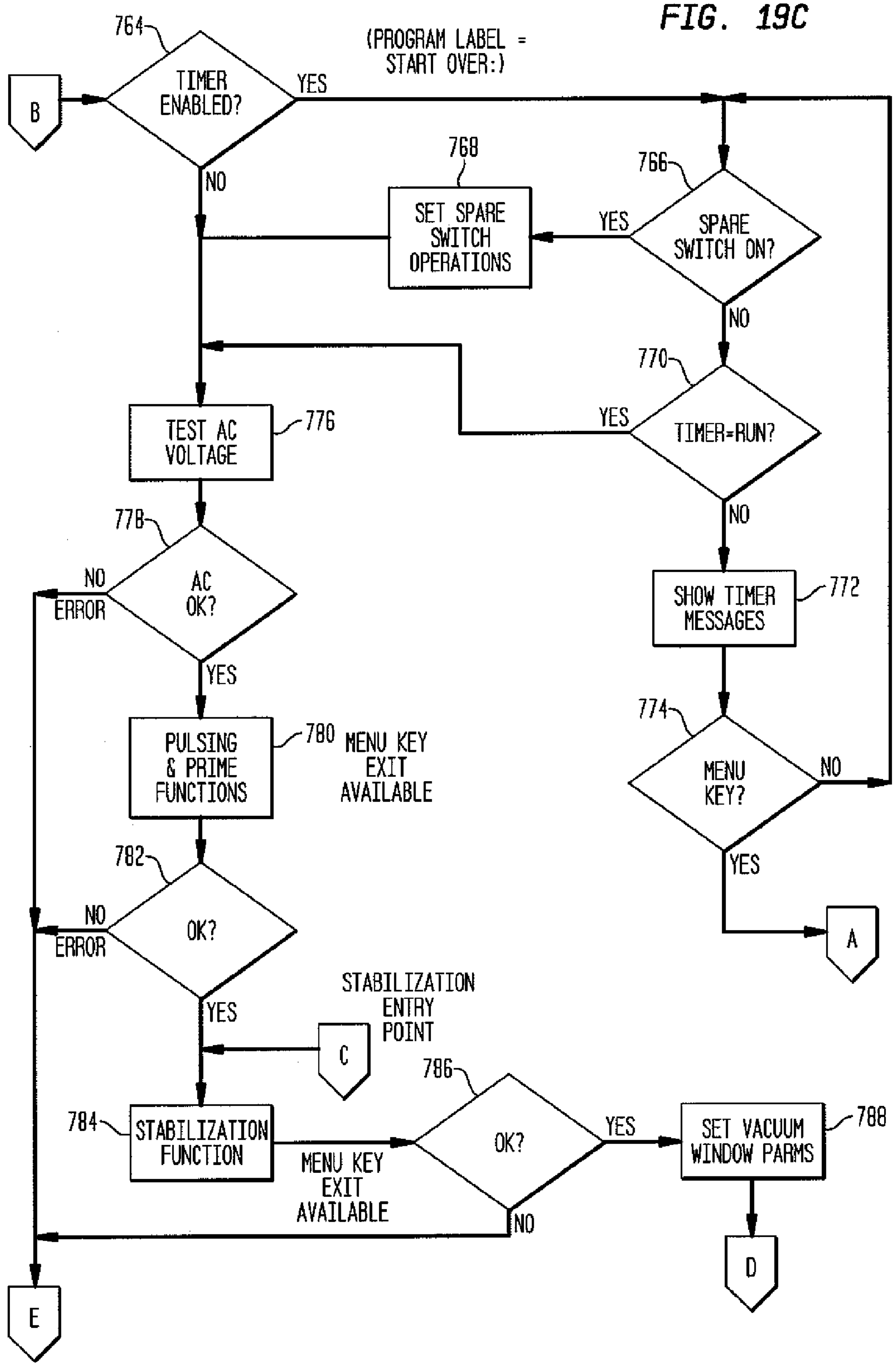
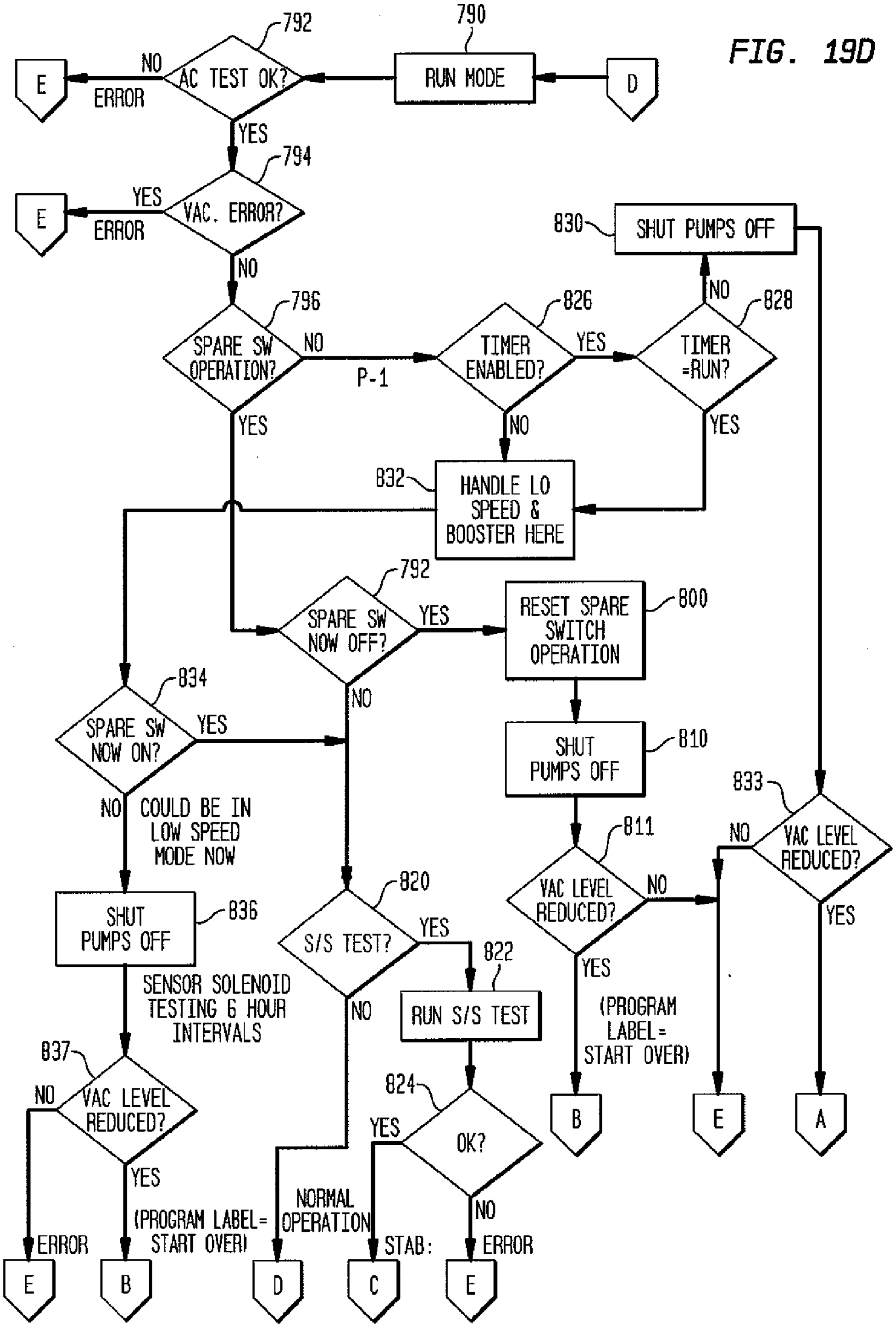

2
TIMEOUT AFTER 5 SECONDS
744
SET TIME-DATE?
Y KEY
746
SET TIME & DATE FUNCTION
N KEY
TIMEOUT AFTER 5 SECONDS
748
SET TIMER EVENTS?
Y KEY
750
SET TIMER EVENTS FUNCTION
DIP4 OFF
N KEY
TIMEOUT AFTER 5 SECONDS
752
POOL TECH MODE?
N KEY
DOUBLE CLICK OK KEY
754
CUSTOM INSTALLATION FUNCTIONS
Y KEY
756
POOL TECH MODE FUNCTIONS
DISPLAY DATE/TIME
758
(PROGRAM LABEL= RUN NORMAL FOR NOW:)
762
760
ACTIVE POOL TECH MODE?
YES
SHOW SPECIAL POOL TECH MESSAGES
THIS CAN BE SET IN POOL TECH MODE FUNCTIONS
NO
B

FIG. 19C



(PROGRAM LABEL = START OVER:)
B
764
TIMER ENABLED?
YES
NO
768
SET SPARE SWITCH OPERATIONS
766
SPARE SWITCH ON?
YES
NO
770
TIMER=RUN?
YES
NO
776
TEST AC VOLTAGE
778
AC OK?
NO ERROR
YES
772
SHOW TIMER MESSAGES
774
MENU KEY?
NO
YES
A
780
PULSING & PRIME FUNCTIONS
MENU KEY EXIT AVAILABLE
782
OK?
NO ERROR
YES
STABILIZATION ENTRY POINT
C
786
OK?
YES
NO
784
STABILIZATION FUNCTION
MENU KEY EXIT AVAILABLE
788
SET VACUUM WINDOW PARMS
D
E

FIG. 19D



790
RUN MODE
D
792
AC TEST OK?
NO
ERROR
E
YES
794
VAC. ERROR?
YES
ERROR
E
NO
796
SPARE SW OPERATION?
NO
P-1
826
TIMER ENABLED?
YES
828
TIMER =RUN?
NO
830
SHUT PUMPS OFF
YES
NO
YES
832
HANDLE LO SPEED & BOOSTER HERE
792
SPARE SW NOW OFF?
YES
800
RESET SPARE SWITCH OPERATION
NO
834
SPARE SW NOW ON?
YES
NO
COULD BE IN LOW SPEED MODE NOW
810
SHUT PUMPS OFF
833
VAC LEVEL REDUCED?
NO
YES
811
VAC LEVEL REDUCED?
NO
YES
(PROGRAM LABEL= START OVER)
836
SHUT PUMPS OFF
SENSOR SOLENOID TESTING 6 HOUR INTERVALS
820
S/S TEST?
YES
822
RUN S/S TEST
NO
837
VAC LEVEL REDUCED?
NO
YES
824
OK?
YES
NO
ERROR
(PROGRAM LABEL= START OVER)
NORMAL OPERATION
STAB:
ERROR
E
B
D
C
E
B
E
A

FIG. 19E

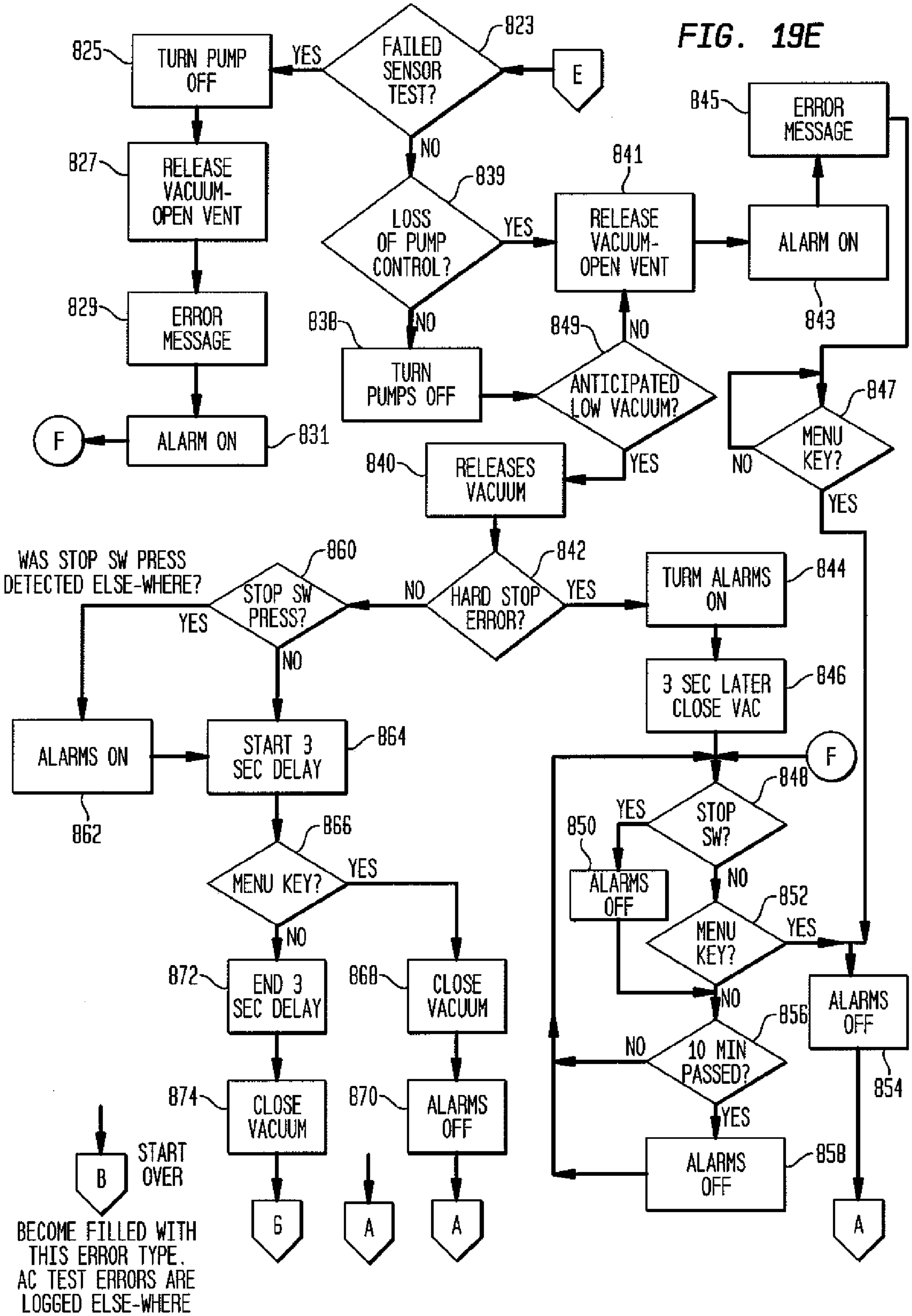
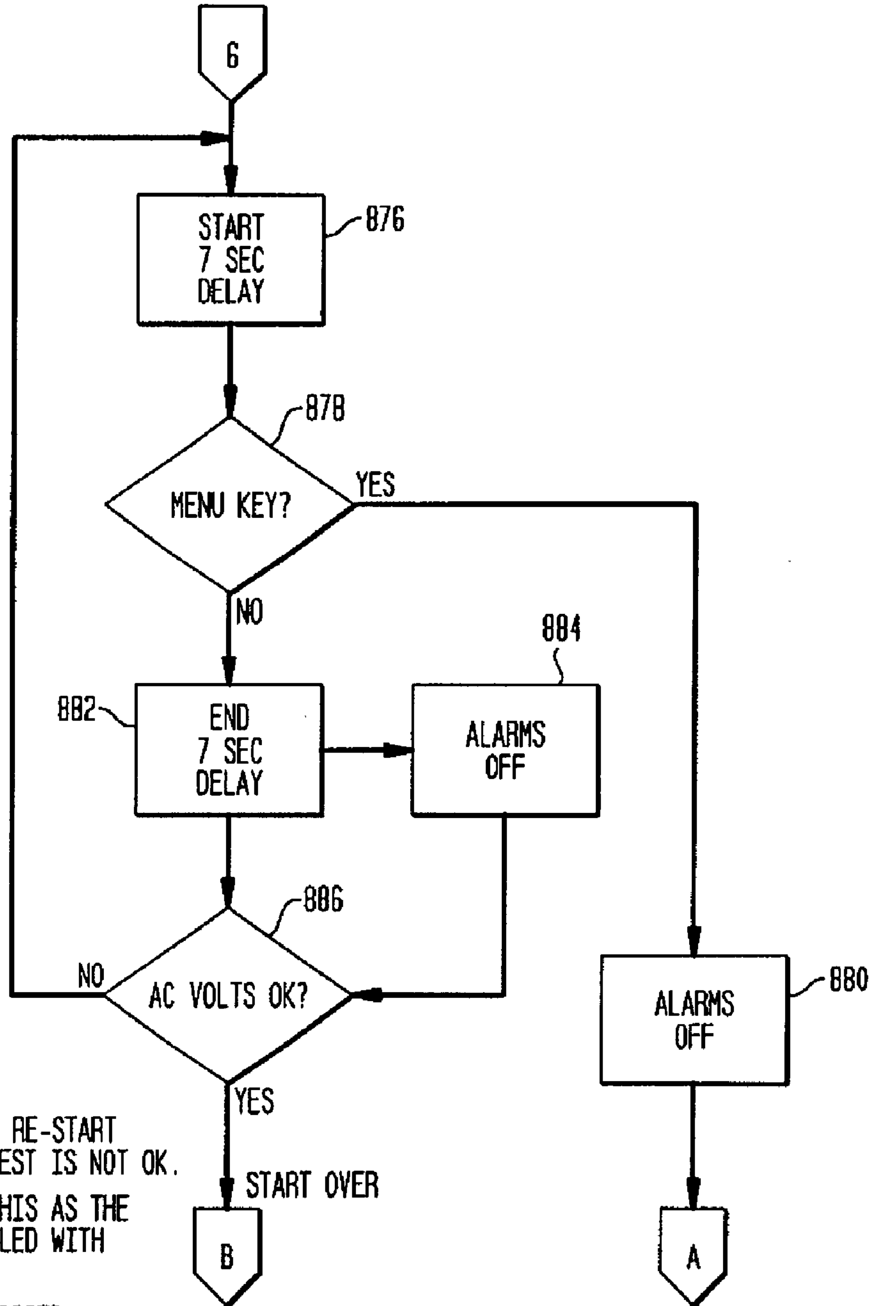

FAILED SENSOR TEST?
823
E
YES
NO
825
TURN PUMP OFF
827
RELEASE VACUUM-OPEN VENT
829
ERROR MESSAGE
831
ALARM ON
F
839
LOSS OF PUMP CONTROL?
841
RELEASE VACUUM-OPEN VENT
843
ALARM ON
845
ERROR MESSAGE
838
TURN PUMPS OFF
849
ANTICIPATED LOW VACUUM?
840
RELEASES VACUUM
847
MENU KEY?
842
HARD STOP ERROR?
844
TURN ALARMS ON
846
3 SEC LATER CLOSE VAC
860
STOP SW PRESS?
WAS STOP SW PRESS DETECTED ELSE-WHERE?
862
ALARMS ON
864
START 3 SEC DELAY
866
MENU KEY?
872
END 3 SEC DELAY
874
CLOSE VACUUM
868
CLOSE VACUUM
870
ALARMS OFF
848
STOP SW?
850
ALARMS OFF
852
MENU KEY?
854
ALARMS OFF
856
10 MIN PASSED?
858
ALARMS OFF
B
START OVER
BECOME FILLED WITH THIS ERROR TYPE. AC TEST ERRORS ARE LOGGED ELSE-WHERE
G
A

FIG. 19F



NOTE: DO NOT WANT TO RE-START IF THIS NO LOAD AC TEST IS NOT OK.

DO NOT WANT TO LOG THIS AS THE LOG COULD BECOME FILLED WITH THIS ERROR TYPE.

AC TEST ERRORS ARE LOGGED ELSE-WHERE.

DRAIN SAFETY AND PUMP CONTROL DEVICE WITH VERIFICATION

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a continuation-in-part of U.S. patent application Ser. No. 11/601,588, filed Nov. 17, 2006, entitled Drain Safety and Pump Control Device, which claims the benefit of U.S. Provisional Patent Application No. 60/817,473, filed on Jun. 29, 2006, the disclosures of which are incorporated herein by reference in their entirety.

FIELD OF THE INVENTION

[0002] The present invention relates to apparatus and methods for preventing persons, animals or things from being injured by the suction exerted on them by water flowing into a drain, in particular that associated with a fluid circulation system in a bathing receptacle such as a swimming pool or spa. Besides its safety function in preventing injury through drain suction acting on a person or thing, the present invention also L controls and prevents damage to water circulation devices, such as pumps, and may be used to control timed operation of water circulation devices.

BACKGROUND OF THE INVENTION

[0003] Various apparatus have been proposed for preventing injury due to drains in fluid-containing vessels, such as pools and spas, including those which sense a pressure change in the conduit extending from the drain to the pump that draws water from the drain and through the conduit. In response to pressure changes indicating an obstruction of the drain, prior art devices exist which reduce vacuum present in the drain-to-pump conduit by, e.g., turning the pump off and/or opening the conduit to the atmosphere. Notwithstanding, there is a need for improved drain safety protection devices that are operational for different types of drain installations, e.g., those on above-ground and below-ground pools and spas, as well as protection devices which do not interfere with the normal operation of fluid circulation systems as are typically encountered in pools and spas, e.g., during the normal cycling of filter/pump systems on and off, during the establishment of prime condition and during speed changes for pumps. Due to laws pertaining to the running of pumps at higher and lower rates of speed to increase economical operation and diminish the use of electricity, it is desirable to have a drain safety protection device that is capable of maintaining safety through speed changes. Further, it is always an objective to improve the reliability and operability of safety equipment, such as drain safety devices.

SUMMARY

[0004] The limitations of prior art drain safety and pump control devices and methods are addressed by the present invention, which includes a fluid circulation system having a motor-driven pump. A sensor senses operational parameters of the fluid circulation system indicative of the operational state of the pump. A computer receives the output of the sensor and is programmed with a control program and data representing a plurality of criteria values corresponding to a plurality of potential functional states of the pump. The program compares sensor output to the criteria values and selectively generates control output to the pump to control the operation of the pump, thereby defining an intended pump state. The program checks output from the sensor to verify that the actual functional state of the pump is consistent with the intended pump state and terminating pump operation when an inconsistency exists.

[0005] In one embodiment of the present invention, the control system features a vent valve communicating with the suction side of the pump. In the event of an inconsistency between the expected and actual functional state of the pump, the vent valve is opened to release vacuum on the suction side of the pump.

[0006] In another embodiment of the invention, a priming time criteria is derived from empirical priming time measurements.

[0007] In yet another embodiment, pressure criteria pertaining to vacuum/pressure on the suction side of the pump may be adjustable based upon changes in fluid flow resistance through the system.

BRIEF DESCRIPTION OF THE FIGURES

[0008] FIG. **1** is a schematic diagram of a below-grade fluid containment vessel and fluid circulation system with drain safety and pump control apparatus in accordance with a first embodiment of the present invention.

[0009] FIG. **2** is a schematic diagram of an above-grade fluid containment vessel and fluid circulation system with drain safety and pump control apparatus in accordance with a second embodiment of the present invention.

[0010] FIG. **3** is a perspective view of an accumulator in accordance with a third embodiment of the present invention.

[0011] FIG. **4** is a cross-sectional view of the accumulator of FIG. **3** taken along section line IV-IV and looking in the direction of the arrows.

[0012] FIGS. **5** through **8** are graphs showing fluid circulation functions and associated vacuum levels related to time.

[0013] FIG. **9** is a diagram of data structures for storing selected vacuum level and vacuum range data for various fluid circulation functions and at various times.

[0014] FIGS. **10**A-**10**D and **11**A-**11**B are circuit diagrams of a controller in accordance with an exemplary embodiment of the present invention.

[0015] FIG. **12** is a schematic diagram of a drain safety and pump control apparatus in accordance with a third embodiment of the present invention for use with a fluid containment vessel and fluid circulation system.

[0016] FIG. **13** is a schematic diagram of a drain safety and pump control apparatus in accordance with a fourth embodiment of the present invention as used with an above-grade fluid containment vessel.

[0017] FIG. **14** is a front view of a control system of the drain safety and pump control apparatus of FIG. **12** with the enclosure door opened to show the operator panel.

[0018] FIG. **15** is a front view of the control system of FIG. **14** with the enclosure door and operator panel thereof removed.

[0019] FIGS. **16**A and **16**B show wiring and terminal diagrams for connecting electrical power and pumps to the control system of FIG. **14**.

[0020] FIG. **17** is a cross-sectional view of an accumulator in accordance with an embodiment of the present invention.

[0021] FIG. **18** is a perspective view of a line tapping assembly for connecting a vacuum line to a suction conduit in accordance with an embodiment of the present invention.

[0022] FIGS. **19***a*-**19***f* are flowcharts illustrating functionality of an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0023] FIG. **1** shows a pool/spa system S with a fluid containment vessel V, such as a pool or spa. The containment vessel V is below ground level G as would be common for in-ground pools and spas. The pool/spa system S has a fluid circulation system **10** including one or a plurality of drains **12**, **14** at the bottom **16** thereof which communicate with a drain conduit **18** that extends to a valve **20**. Alternatively, for smaller pools, a single drain may be used. An upper level drain **22**, such as a skimmer, communicates with a corresponding drain conduit **24** that terminates at valve **26**. The outlets of the valves **20** and **26** are plumbed to a common suction conduit **28** extending from the valves **20**, **26** to a strainer basket **29**. The strainer basket **29** discharges into the inlet of a pump **30**. The pump **30** discharges into outlet conduit **32** which extends to the inlet of a filter **34**. The filter **34** discharges into return conduit **36** which discharges filtered water into the vessel V via a return outlet **38**. A vacuum release system **39** is provided to release/reduce vacuum present in the fluid circulation system **10** in response to anomalies such as drain occlusion. More particularly, the outlet conduit **32** has a branch **40** which extends to a vent valve **42**. The vent valve **42** is a solenoid valve that is electrically operated to transition between opened and closed positions, opening the branch **40** to the atmosphere. Alternatively, the vent valve may be actuated by vacuum and/or by pressurized gas (e.g., pneumatic) or fluid (hydraulic). An alternative and/or redundant vent valve **44** may be provided to control venting of atmosphere into suction conduit **28**. A vacuum sensor **46** is inserted into the suction conduit **28**, the vacuum signal of which is transmitted to a controller **48** via line **50**. The sensor **46** may be of the solid-state piezoelectric crystal or diaphragm type having an electrical output in the form of a change in resistance to electrical current or an output in volts or millivolts. This type of vacuum sensor **46** can be installed in the suction conduit **28** by means of a threaded fitting or a saddle fitting. Alternatively, a vacuum line extending from a vacuum transducer (not shown) positioned on or proximate to the controller **48** and extending to the suction conduit **28** may be employed. If a vacuum line is employed, kinking of the line must be prevented and the distance between the vacuum conduit **28** and the transducer must not exceed that which would permit an accurate vacuum signal from being conducted along its length. In the situation where a vacuum line extends from the suction conduit **28** to a vacuum transducer at the controller **48**, the vacuum line may communicate with the vent valve **44**, such that when the vent valve **44** is opened to the atmosphere, the air rushes into the vacuum line and on to the suction conduit **28** to release/reduce the vacuum level present in the suction conduit **28** and the drains **12**, **14** in communication therewith. In this instance, the vent valve **44** may have at least two positions, a first wherein the transducer is exposed to vacuum in the suction conduit (a vacuum sensing position) and a second which vents the suction conduit to atmosphere (a venting position). A suitable vent valve **44** for this application can be obtained from SMC Corporation of America, of Indianapolis, Ind., Model No. VXV3130.

[0024] The controller **48** receives power from a utility supplied power line **52**, which extends to a circuit breaker box **54**. The controller **48** switches power to the pump **30** on and off via power line **56** and also controls the position of the valves **42**,**44** via control lines **58**, **60**. The occlusion of one of the drains **12**, **14** or **22**, will trigger a change in the vacuum level present in suction conduit **28**. A change in vacuum level is sensed by the vacuum sensor **46** and by the controller **48**, which can then respond by opening valves **42**, **44** to atmosphere and disrupting power to pump **30**. In this manner, suction at the drains **12**, **14** and **22** is released allowing any obstruction to be cleared. For example, if a swimmer were to become caught on the main drain **12**, the resultant release of suction owing to the venting of the suction line **28** to atmosphere and the discontinuance of pumping will allow the swimmer to remove himself from the main drain **12**. Besides executing a drain protection safety function, the controller **48** may also be used to control the times when the pump **30** is operated pursuant to a schedule, as well as when the pump **30** is operated at different speeds. On start-up, the pump in some pool/spa installations requires time to establish a prime, viz., the filling of the suction conduit, strainer and pump housing with water. This is normally accomplished by running the pump at high speed. The pump speed (and associated power consumption that is required to prime the pump) is more than that which is required to maintain effective filtration/circulation once prime has been established. Some states have recently passed laws that require pools and spas to have pumps that are operated at two speeds, namely, at high speed to perform certain functions, such as priming and cleaning, and low speed to conduct filtration at a reduced usage of electrical power. The vacuum release system **39** of the present invention monitors for and responds to vacuum anomalies while pump speed changes are executed. The controller **48** has a display **62** and input keys **64** for an operator interface, allowing the operator to read messages presented on the display **62** by the controller and to provide input, such as selecting menu choices, answers and/or values by pressing selected keys. Some pool/spa systems may have a preexisting controller **65** that controls heating, circulation/filtering, cleaning, chlorination, etc. The controller **48** may be connected to a preexisting controller **65** for the purpose of utilizing the scheduling data entered into the controller **65**, thereby acting as an intermediary or co-controller.

[0025] The return line **36** has a branch **66** which communicates with the inlet of an optional booster pump **68** that is used to increase the pressure of the fluid from the return line **36** to aid in operating a pressure-type pool cleaner **74**. Some pools are equipped with automatic cleaners that utilize the return flow of water from the filtration system to drive various pressure cleaner devices. In some pool systems, the filtration/circulation pump **30** is switched to high power to generate a pressurized flow that is effective at driving a pressure cleaner **74**. Still other pool systems utilize a booster pump **68** to increase the pressure of the return flow of water to enhance the effectiveness of a pool cleaner **74** during cleaning mode. The vacuum release system **39** of the present invention is capable of monitoring drain occlusion and pump malfunction while pool cleaning is occurring and during the transitions from normal filtration running to cleaning mode and from cleaning mode back to normal filtration. The outlet of the booster pump **68** discharges into conduit **70** that is connected to a flexible hose **72** leading to the cleaner **74**. Power to the booster pump **68** via line **75** may be controlled by controller **48**, manually, or by controller **65**. A stop switch **76** may be provided with the vacuum release system **39** or an existing stop switch **76** may be employed to signal the controller **48** that an emergency shut down has been ordered. The stop switch **76** may be a normally open switch maintaining electrical continuity in a conductive loop. When pressed, continuity is disrupted, signaling an emergency shut-down.

[0026] FIG. **2** shows a pool/spa system S' with a fluid containment vessel V' that is above ground level G', as would be common for above-ground pools and spas. The pool/spa system S' has a fluid circulation system **110** with one or more drains **112** at the bottom **116** thereof which communicate with a drain conduit **118** that extends to a valve **120**. An upper level drain **122**, such as a skimmer, communicates with a corresponding drain conduit **124** that terminates at valve **126**. The outlets of the valves **120** and **126** are plumbed to a common suction conduit **128** extending from the valves **120**, **126** to a strainer basket **129**. The strainer basket **129** discharges into the inlet of a pump **130**. The pump **130** discharges into outlet conduit **132** which extends to the inlet of a filter **134**. The filter **134** discharges into return conduit **136** (shown broken and labeled R) which discharges filtered water into the vessel **110** via a return outlet **138**. A vacuum release system **139** releases/reduces vacuum present in the fluid circulation system **110** in response to anomalies such as drain occlusion. More particularly, the outlet conduit **132** has a branch **140** which extends to a one-way check valve **143**. The check valve **143** allows fluid flow away from the pump **130** only, but not towards the pump **130**. The check valve **143** discharges via conduit **145** to an accumulator **147**. The accumulator **147**, which functions to store fluid under pressure, includes a pressure vessel containing a resilient member **149**, such as a spring, a pocket of air, or an elastomeric material acting against a piston **151**. The pump **130** pushes fluid under pressure through the filter **134** and also through the check valve **143** into the accumulator **147**, where it displaces the piston **151** against the pressure of the resilient member **149**. The pressure developed in the accumulator **147** is stored (even when the pressure in outlet conduit **132** drops) due to the resistance to reverse flow attributed to the check valve **143**. An outlet conduit **153** extends from the interior of the accumulator **147** (in communication with the pressurized fluid therein) to a solenoid controlled valve **155** that is opened and closed under the control of controller **148**. A vacuum sensor **146** is inserted into the suction conduit **128**, the vacuum signal of which is transmitted to the controller **148** via line **150**. The sensor **146** may be of the same types as described above for sensor **46**. Alternatively, a vacuum line extending from a vacuum transducer positioned on or proximate to the controller **148** to the suction conduit **128** may be employed. The sensor **146**, or the alternative vacuum line, is preferably located in proximity to the inlet of the pump **130** on a straight run of pipe at about 45 degrees from the top of the pipe. This position minimizes fluctuations due to aspiration of air. As described above in relation to FIG. **1**, when a vacuum line is used to transmit vacuum from the suction conduit **128** to a transducer mounted on the controller **148**, the suction line may have a dual function. More particularly, instead of valve **155** discharging into conduit **157**, it may discharge into the vacuum line, which communicates with the suction conduit **128**. As in the first embodiment, the valve **155** may have at least two positions, a sensing position where the transducer is in communication with the suction conduit **128** and a vacuum release position placing the suction conduit in communication with the accumulator **147** (through the vacuum line).

[0027] The controller **148** receives power from a utility supplied power line **152**, which extends into a circuit breaker box **154**. The controller **148** switches power to the pump **130** on and off via power line **156** and also controls the position of valve **155** via line **158**. The occlusion of one of the drains **112** or **122** will trigger a change in the vacuum level present in suction conduit **128**. A change in vacuum level is sensed by the vacuum sensor **146** and by the controller **148**, which can then respond by opening valve **155** permitting the accumulator **147** to discharge the pressurized fluid contained therein into the suction conduit **128** to pressurize the suction conduit **128** and relieve any vacuum condition that may have previously existed due to an occluded drain. As used herein, the term "fluid" shall have its broadest meaning, encompassing a liquid, such as water, and a gas, such as air. For example, the fluid discharged by the accumulator **147** may include both air and water. The controller **148** also disrupts power to pump **130** to prevent the reestablishment of a vacuum condition in suction conduit **128**. In this manner, suction at the drains **112** and **122** is released/reduced allowing any obstruction to be cleared. For example, if a swimmer were to become caught on main drain **112**, the resultant release of pressurized fluid from the accumulator **147** into the suction line **128** and the discontinuance of pumping will allow the swimmer to remove himself or herself from the main drain **112**. As in the previous embodiment, besides executing a drain protection safety function, the controller **148** may also be used to control the times when the pump **130** is operated pursuant to a schedule, as well as when the pump **130** is operated at different speeds.

[0028] FIGS. **3** and **4** show an accumulator **247** having an elongated cylindrical body **259** and a threaded cap **261** with a pair of handles **263**, **265** for tightening the cap **261** onto the body **259**. A spring **267** extends between the cap **261** and a piston **269** with a ring seal **271**. An inlet orifice **273** admits fluid under pressure into the interior of the accumulator, where it displaces the piston **269** against spring pressure. As noted above, the spring **267** could be replaced with any resilient member, such as sealed bladder containing a gas, or body made from an elastomeric material.

[0029] Each pool/spa system will have different operating characteristics, e.g., vacuum levels in the suction conduits **28**, **128**, depending upon many factors, such as pool size, water height above ground level, number and size of drains, conduits, pumps, etc. This is true of normal, unobstructed operation during the various functions performed by the system, as well as during degraded operating mode due to the accumulation of debris in filters and skimmers and when experiencing malfunctions due to obstruction or disconnection of a drain line. The vacuum level in the suction conduits **28**, **128** will also vary widely depending upon the functional state that the fluid circulation system is in at any given time: start-up; stabilization; filtration; change of speed; and/or cleaning. As a result, it is necessary to ascertain safe and appropriate vacuum levels for all of the various modes of operation of the circulation system, so that the vacuum release systems **39**, **139** are triggered under appropriate circumstances to protect the users and the equipment of the pool/spa system during all phases of operation, while allowing the system to operate in a normal and effective manner.

[0030] The upper portion of FIG. **5** graphically shows various operating states of the in-ground pool/spa system S, which includes the two speed pump **30** and the booster pump **68** running normally and not effected by the vacuum release system **29**. From time T_0 time T_1 the circulation pump **30** is started in high speed to prime the pump **30**. This condition is achieved at or before T_1, whereupon the circulation pump **30** is set to low speed for filtration purposes, i.e., until time T_2. At time T_2, the circulation pump **30** is again set at high speed to increase the pressure of the return flow to aid in operating the pool cleaner **74**. The booster pump **68** is also activated at time T_2 to further increase the pressure of the water reaching the cleaner **74**. When cleaning is terminated at time T_3, the pump **30** goes back to low speed for filtration until time T_4, when the pump **30** is turned off. At time T_5, the pump **30** is restarted as at time T_0. As shown in the lower portion of FIG. **5**, the various states of operation of the pump/circulation system of the pool/spa system S have an associated effect on the vacuum level present in the suction conduit **28** leading to the pump **30**. During the starting phase, there is a rapid ramping up of vacuum to a peak and then stabilization at a lower level while the pump **30** runs at high speed. Upon the pump **30** being set to low speed at time T_1, the vacuum level ramps down to a valley and then recovers to a higher stable level until reaching time T_2. At T_2, the ramping up is repeated, but in this particular installation, the peak vacuum level reached by the combined operation of the pump **30** at high speed and the booster pump **68**, exceeds that reached by the high speed operation of the circulation pump **30** alone. This would not necessarily be true for all installations.

[0031] Previously, pool/spa owners would manually control the functional state of the circulation systems **10**, **110** by, for example, turning the pumps **30**, **130**, **68** on and off, as necessary. Electro-mechanical timers (a clock which mechanically opens and closes contact points) were then used to automatically turn pumps on and off in accordance with a predetermined schedule. More recently, digital programmable controllers, such as the controller **65**, have been utilized to activate pumps and other pool/spa equipment in accordance with a predetermined schedule, which the user enters into the controller **65**. The vacuum release systems **39**, **139** have the capability of working in conjunction with pool systems that are manually controlled, with electromechanically-timed systems and with digitally controlled systems. More particularly, the vacuum release systems **39**, **139** may be utilized on manually controlled circulation systems to convert them to automatic systems, since the vacuum release controllers **48**, **148** have timing and scheduling capability, enabling users to schedule the running and speed of the circulation pumps **30**, **130**, **68** in lieu of turning them on and off manually. Alternatively, the owner of a manual pool/spa system may decline to utilize the timing capabilities of the controllers **48**, **148** and continue to run the circulation system manually. In the latter case, the vacuum release systems **39**, **139** may be used strictly to monitor vacuum levels to promote user safety and prevent equipment degradation (not for pump scheduling). The vacuum release systems **39**, **139** may also be employed with an existing controller which is used to schedule and automatically operate the circulation system.

[0032] As can be seen in FIG. **5**, the functions and vacuum levels associated with different functional states of the circulation systems are time dependent. As a result, the relationship between the vacuum level and time can be used to ascertain appropriate vacuum levels at specific times and/or the appropriate system response to high or low vacuum levels at specific times. For example, if it is known in advance that a high vacuum level is appropriate during a particular phase of operation, then that high vacuum level can be ignored for a certain period, rather than triggering vacuum release.

[0033] There are different methods of ascertaining appropriate and safe levels of vacuum for pool/spa systems during various functional states. One method is to conduct testing on various systems in all possible modes of operation in a laboratory setting to arrive at values with common application. For example, testing may reveal a vacuum level L_D that is above all normal operational levels for any system, i.e., the maximum observed level L_M plus a tolerance. This high limit L_D, may be used as the default criteria for identifying an anomaly, such as an occlusion of the drains **12**, **112**. This default, high limit-type triggering of vacuum release by the vent valves **42**, **44** and/or the accumulator **147** discharge, can be utilized without reference to the particular operational state of the pool/spa system, the identity of the system and/or the scheduling or timing of different functional states. This process of ascertaining a default acceptable vacuum level L_D by exercising a pool/spa system and then observing the resultant vacuum levels can also be applied to determine the maximum observed rate of change of vacuum level (slope) S_M (either rising or falling) and a default acceptable slope S_D for normal safe operation. A default acceptable rate of vacuum change S_D can be calculated from the maximum observed rate of change S_M by adding a tolerance (see FIG. **6**). The slope, e.g., S_M, is determined by subtracting former from subsequent vacuum readings and dividing by the time period expired. A high slope value is indicative of a radical vacuum change, such as that associated with an occlusion of a drain conduit by a person. The actual measured slope Sa during operation of the pump/circulation system can be constantly compared to the maximum slope S_M or the default slope S_D to ascertain that it does not exceed it.

[0034] An alternative and/or supplemental method of ascertaining vacuum level criteria which provides values that are more sensitive to a particular pool/spa system, is to observe and record actual vacuum levels of a given specific pool/spa system during operation, in various states, and then calculate appropriate vacuum ranges and/or high and low limits for the various potential states of that particular pool/spa system. This type of empirical data can be observed and recorded manually and/or automatically captured and/or calculated by the controllers **48**, **148**. One approach for collecting relevant empirical vacuum level data is to run the system in a state which results in maximum normal vacuum levels, e.g., while utilizing a pool vacuum attached to the skimmer **22**.

[0035] In the event that the vacuum release systems **39**, **139** of the present invention are used as a timer/controller for the pump/circulation systems **10**, **110**, respectively, and/or works in cooperation with an existing timer/controller, such as the controller **65**, time and functional phase-based monitoring of vacuum levels is possible.

[0036] FIG. **6** is an enlarged view of start and stabilization phases of operation of a circulation pump. It could be illustrative of a single speed pump, such as the pumps **30**, **130**, or of a two speed pump, such as the pumps, **30**, **130**, started in either high or low speed. The pumps **30**, **130** are started at time T_0 and at time T_1 have developed a vacuum level V_1 in the suction conduits **28**, **128**, respectively. At time T_2, the vacuum level is V_2 and rapidly ramps up to V_4 at time T_4. At time T_3, the rate of change or slope of the actual vacuum reading is S_A. After peaking at time T_4, the vacuum level enters a mildly oscillating stabilized region Rs. Given that the vacuum level V_X at any time T_X can be ascertained and stored, the vacuum level profile at start-up and stabilization could be recorded as a table, array or matrix. The top portion of FIG. **9** illustrates a table of measured vacuum values that the controllers **48**, **148** can store during various phases of operation of the pool/spa systems S, S' at times T_1, T_2 . . . , e.g., on installation by a technician. During stabilized modes of operation, such as filtration mode, which will persist for a substantial period without change, measurements need not be taken beyond the time of stabilization, i.e., T_s, such that the values for the last relevant time period will apply for an indefinite period thereafter. Given recorded data descriptive of vacuum levels over time, this vacuum profile data can be compared to a subsequent operation of the circulation pump when it performs the same process, i.e., start-up and stabilization, and the readings compared between the first obtained data and the second, to test for consistency or anomaly.

[0037] Since there is a great likelihood that the second operation of the pump will generate vacuum readings which are somewhat different than the first operation thereof, a more realistic and meaningful comparison would be between the first recorded vacuum levels +/−a tolerance, such that the determination is whether a second reading falls within a range rather than being exactly equal to, less than or greater than a specific value. As shown in FIG. **9**, the measured values V_1, V_2, etc. can immediately or subsequently be translated into a table of ranges, R**1**, R**2** . . . , against which measured values obtained when the pool/spa system is subsequently run during normal use by the consumer can be compared. Besides monitoring the degree to which the measured vacuum profile is compatible with a normal profile during start-up/priming, the controllers **48**, **148** may also time how long it takes to achieve priming and count the number of times the pumps **30**, **130** fail to achieve a prime condition within a selected time. Failure to achieve prime within a designated time and/or number of attempts will then result in storage of an error event in the event log and appropriate error processing, such as displaying an error message to the operator and/or shutting the circulation systems **10**, **110** down. In accordance with the present invention, the time for priming, e.g., T_s may be determined by measurement, e.g., during the exercise of the system by a technician upon installation. In this instance, the controller **48**, **148** would identify T_s by recording the time from startup T_0 the occurrence of the characteristic mildly oscillating vacuum readings associated with region R_s. This time measurement may be used as a criteria on later priming events to ascertain that priming occurs within an acceptable period. The priming time criteria may also be determined by observing the change/rate of change of the vacuum level. After the vacuum level stabilizes in the mildly oscillating region R_S, it may continue to rise for a further time period, e.g., attributable to "soft-start" venting, described below. The vacuum may therefore be monitored for an additional period and the values tested to ascertain if the vacuum is still changing (increasing). Since the vacuum level has normal variations (oscillations) after priming, there will always be variations from one reading to the next. For that reason, examination of the magnitude of the change or rate of change provides insight as to whether priming has been completely accomplished. The stable running vacuum level present after fully priming the pump is an accurate starting value about which to calculate the permissible vacuum range for stable running, i.e., the criteria range outside of which an anomaly is inferred by the controller **48**, **148**. As an alternative to automatic priming time criteria determination, the timing criteria for priming may be observed and recorded by a technician during start-up of the system S, S'. As yet a further alternative, the timing criteria that is either automatically measured or that is measured by a technician may be programmatically or manually expanded by adding a time tolerance. For example, if a particular system S takes fifteen seconds to prime when the system S is run for the first time after installation, then a time tolerance of an additional thirty seconds may be added to formulate a priming time criteria of forty-five seconds. In this manner, the expanded time criteria may be utilized to allow the system S additional time to prime, e.g., due to diminished efficiency of water movement through the filter **34** attributable to debris build-up in the filter **34**. Because the priming time criteria is empirically based, the present invention is adaptable to a wide range of systems S, S', having different attributes, e.g., that take a variety of different times to achieve prime.

[0038] As yet a further alternative, the present invention may continually adjust the priming time criteria based upon sensed empirical data, e.g., to compensate for changing conditions in the system S, S', such as a filter **34** that provides changing resistance to fluid flow due to debris accumulation/removal and therefore changing amounts of time required to achieve priming. More particularly, the priming time criteria may be adjusted upward and downward based upon the measured time Ts for each occurrence of priming. For example, if the priming time criteria is ascertained by empirically measuring a fifteen second time for priming on a newly installed system and expanded by adding thirty seconds for a first priming time criteria of forty-five seconds, then on a subsequent priming cycle the measured actual time for priming is twenty seconds, the controllers **48**, **148** may conclude that priming occurred within an acceptable time. However, the longer measurement (twenty seconds rather than fifteen seconds) may be indicative of a gradual, normal system change, so the controller **48**, **148** may add five additional seconds to the priming time criteria (resulting in fifty seconds) to adapt to this change. These incremental changes can be utilized to move the criteria range to accommodate expected changes in function of the system S, S'. The adjustment in priming time criteria implies, however, that a maximum priming time criteria value should be established beyond which no incrementation can be permitted, e.g., representing a maximum limit of time that a pump **30**, **130** can be run without achieving prime to avoid damaging the pump **30**, **130**. For example, using an automatically adjusting priming time approach, a maximum priming time criteria could be set at three minutes. On each priming cycle, after measuring the actual time required for priming, the controller **48**, **148** may test to ascertain that the adjustment results in a priming time criteria value less than or equal to three minutes. If so, then the incrementation/adjustment to the priming time criteria is permitted, otherwise, the priming time is set to the maximum, i.e., three minutes. Accordingly, if the time for priming exceeds three minutes, then an error is generated and processed. In addition to adjusting the priming time upward (increasing the priming time criteria), the priming time may be adjusted downwardly, due to a measured priming time that is less than the previously measured priming time. For example, if backwashing of the filter **34**, **134** results in a priming time which is ten seconds less than the previously measured priming time, then the priming time criteria can be reduced by ten seconds. One simple formula for calculating the priming time criteria on the next priming cycle is: actual measured time for priming, plus the expansion factor, equals the priming time criteria, but only if the resulting priming time criteria is less than or equal to the maximum possible priming time criteria, otherwise, the priming time criteria equals the maximum possible priming time criteria.

[0039] Referring again to FIG. **6**, in addition to the default anomaly vacuum level, L_D, and default rate of change/slope S_D, parameters such as, ultra-safe high and low vacuum limits L_H and L_L, respectively, and slope Ss can be identified, which are assured to be sensitive to anomalies, since they are violated during normal operation of the pump/circulation system. Exceeding the ultra-safe L_H, L_L and S_S limits can be acted upon or ignored based upon the timing/functional context in which it occurs. For example, exceeding the low limit L_L between T_0 and T_1 can be ignored given that the controller is "aware" that the within this timeframe, L_L must be violated. By way of another example, the peak vacuum between T_2 and T_4 that exceeds the high limit L_H can be ignored because it is expected. Alternatively, exceeding the high limit L_H or slope S_S may trigger vacuum reduction by the system by de-powering the pumps **30**, **130**, venting to atmosphere via the valves **42**, **44**, or releasing accumulated pressure in the accumulator **147** into the conduit **128** until the vacuum level falls below L_H and/or slope decreases below S_S. In this case, the vacuum release systems **39**, **139** are not used merely as emergency systems when a very high, unexpected spike in vacuum occurs which violates L_D and/or S_D; but rather, they operate constantly, affecting vacuum during normal operation of their respective pump/circulation systems. In this manner, the vacuum release system is constantly operational and is being exercised and tested. Furthermore, the trigger level of vacuum/rate of change is of a smaller magnitude, resulting in a system which is more sensitive to anomalies and to activities that can lead to emergencies but have not yet done so.

[0040] The maximum slopes S_D and S_S are alternative and/or cumulative criteria that may be applied to control the system based on vacuum readings. As with triggering vacuum release based upon a vacuum level criteria, such as L_D, an excessive actual slope S_A can be ignored for a short time if it falls into a predictable and expected time frame relative to the particular function being executed. Alternatively, the excessive slope S_A can trigger vacuum release if using ultra safe criteria S_S.

[0041] The actual slope S_A can be used to indicate the stabilization of a pump (acquisition of prime) such as is illustrated in stabilization region R_S in FIG. **6**, in that the slope readings will be of relatively low magnitude, pass through zero, and will oscillate in sign. Another way of characterizing the stabilization region R_S is that the difference between successive readings is small, indicating that prime has been achieved. While the same can be true of a run-dry condition, a prime condition can be distinguished from a run-dry condition in that a prime condition will exhibit a substantially higher vacuum level than that which is prevalent during a run-dry situation. The stabilization region R_S can be detected based upon the foregoing and therefore the time necessary for the particular system to acquire stabilization after start-up, i.e., time Ts, can be observed and recorded.

[0042] FIG. **7** illustrates another approach to vacuum release/reduction that the vacuum release systems **39**, **139** may employ on start-up, as well as at other times, such as filtration. In FIG. **7**, the system triggers vacuum release/reduction through venting by the valves **42**, **44** or by discharge of the accumulator **147** on a periodic basis, i.e., at T_{V1}, T_{V2}, T_{V3} and T_{V4} over a selected period of time (between T_O and T_S) known empirically to be required to establish prime in the particular system in question. Vacuum release/reduction occurs automatically/programmatically at times T_{V1} through T_{V4}, altering the vacuum profile, e.g., from that which appears in FIG. **6**. When the pumps **30**, **130** are started, e.g., for the first time or at any subsequent time after a pump "off" condition, such as during the normal on/off cycling of the pumps **30**, **130**, the controller opens the vent valve **44** several times in succession, e.g., once every 3 seconds to "soft start" the system and to warn swimmers/bathers that the fluid circulation systems **10**, **110** have been turned on. Alternatively, soft starting can be accomplished in above-ground pools by periodically activating the accumulator release valve **155**. During "soft starting", the pumps **30**, **130** are not subjected to the inertia of a solid column of fluid present in the drain lines **18**, **118** leading to the pumps **30**, **130**, respectively, but instead may draw air or pressurized water into the suction conduits **20**, **128** to lighten the load on the pumps **30**, **130**, respectively. Swimmers/bathers are warned of pump activation by the sound and appearance of air bubbles and/or intermittent flow being ejected from the return line into the pool or spa. On start-up, a test of the of the vacuum sensors **46**, **146** is conducted by determining that a zero vacuum pressure signal is present when the valves **44** or **155**, are open and a minimum signal (greater than zero) is obtained during the pump priming cycle when such valves are closed. When the solenoid-controlled valves **44**, **155** are being tested, a factory and/or technician set maximum vacuum limit, e.g., L_D (default High Spike vacuum setting) based on the pool configuration provides protection to pool/spa users. If the default high vacuum limit setting L_D is exceeded, the solenoid controlled valves **44**, **155** are activated, venting the suction conduits **28**, **128** to atmosphere or the accumulator **147** and the pump(s) **30**, **130** are shut down. Otherwise, the circulation systems **10**, **110** proceed to stabilize R_S. As shown in FIG. **7**, when soft starting/periodic vacuum releases are used, the time for establishing stability T_S is slightly delayed over that shown in FIG. **6** (normal priming), but the vacuum level never exceeds the ultra-safe high limit L_H.

[0043] A similar profile as is exhibited in FIG. **7** would be generated by the vacuum release systems **39**, **139** sensing upon rates of change in pressure, i.e., exceeding an ultra-safe maximum slope Ss and/or preventing vacuum levels beyond L_H, interactively. For example, the profile shown in FIG. **6** would generate a vacuum release/reduction at T_3 attributable to an excessive rate of change of the vacuum level (excessive slope) at T_3. This would have a similar effect on the vacuum level as that occurring at T_{V3} in FIG. **7**.

[0044] After the acquisition of prime, and, if applicable, the setting of the pump speed to low speed for filtering operation, the pumps **30**, **130** will continue to run at a given speed for a predetermined time, as determined by the technician and/or user based upon factors such as pool use patterns, exposure to wind borne debris, such as dust and leaves, all of which will vary for each installation. As noted above, the length of operation of the pumps **30**, **130** will be determined either manually or by a timer, i.e., either that present in the controllers **48**, **148** of the present invention or by another timer/controller, e.g., the controller **65**, installed on the pool/spa system. During filtration, the vacuum level in the suction conduits **28**, **128** is stabilized and will typically stay within a range of approximately +/−0.5 inches of mercury. Minor variations in vacuum level are common due to the occasional presence of debris, such as leaves on the main drain cover or due to a person passing by or walking on the main drain cover. Because it would not be desirable to shut the system down permanently due to minor variations in vacuum due to predictable and harmless events during normal operation, shutdown is preferably only triggered by a vacuum spike or rate of change that exceeds the selected limit, e.g., L_H, L_D, S_S or S_D, and which is predictive of a malfunction, such as occlusion of a drain by a person or an object. Vacuum measurements are taken at about 1000 samples per second and groups of 10-100 consecutive measurements are averaged, yielding a measured average vacuum level adjustable from one hundredth of a second to every one tenth of a second. These measured average vacuum levels are monitored for a rate of change exceeding the selected limit, e.g., S_S or S_D, such as 40 inches of water per second, which would signal an anomaly and cause the controller to enter the Vacuum Anomaly Detected state. By way of further example, any measured vacuum level exceeding 3.0" Hg above a vacuum value predetermined as a normal running vacuum L_M, will trigger the Vacuum Anomaly Detected state. As noted above, ultra-safe vacuum criteria can be employed and violations of same are considered within the time/function context and auto restart of the pumps **30**, **130** a set number of times is employed. Continuous operation of the pumps **30**, **130** in filtration mode may be periodically interrupted by a self-test, wherein the solenoid valves **44**, **155** are opened to vent the suction conduits **28**, **128**, respectively, to atmosphere or to the accumulator **147**, thereby causing a drop in vacuum level in the suction conduits **28**, **128**. The motor circuitry of the pumps **30**, **130** can also be tested at this time. If the vacuum level does not respond in the expected manner (drops), e.g., greater than or equal to ½" Hg in response to the opening of the solenoid valves **44**, **155**, filtration mode is terminated, the event is recorded in an event log, and Vacuum Anomaly Detected mode is entered. Testing can also be initiated by the owner or technician by depressing the "TEST" momentary switch.

[0045] Vacuum Anomaly Detected Mode

[0046] Upon detection of a vacuum anomaly, the solenoid valves **42**, **44**, **155** are de-activated within 0.1 seconds, allowing the suction conduits **28**, **128** to vent to atmosphere and/or permitting pressurized water stored in the accumulator **147** to enter into the suction line **128**. The valves **42**, **44**, **155** are closed when powered and opened when deactivated. If the solenoid valves **42**, **44**, **155** are closed in an activated state and opened in a deactivated state, a power failure will result in the opening of the solenoid valves **42**, **44**, **155**. In this manner, an entrapment occurring contemporaneously with a power shutdown, e.g., through a power outage or due to a person pulling the main circuit breaker **54** to the pool in an effort to free someone from a drain, will result in vacuum release. Of course, the alternative setup could be employed, viz., a solenoid valve **42**, **44**, **155** that is closed when depowered and opened when powered. This alternative may be preferred in systems which are sensitive to the introduction of air, such as those employing DE filters and/or those in which it is difficult to achieve a prime condition. As to the latter, the prime will not be lost by opening the solenoid valve **42**, **44**, **155**, each time the system is shut down.

[0047] Upon detection of a vacuum anomaly, power to the pumps **30**, **130** could be terminated by the controllers **48**, **148**, respectively. These actions permit a swimmer/bather to free himself/herself from any drain that they have obstructed. If the vacuum release systems **39**, **139** are set to trigger a pump off and vacuum release in response to relatively mild vacuum level changes (ultra-safe mode), after a delay of about thirty seconds, the pump is restarted in Startup mode. The solenoid valve(s) **44**, **155** are deactivated periodically during startup to provide a soft start and to warn swimmers of the starting of the pumps **30**, **130**. The delay on restarting and the soft start provides the swimmer/bather with additional opportunities to get clear of any drains, such as the drains, **12**, **14**, **112**. Each time an anomaly is detected, it is appended to the event log stored in the controllers **48**, **148**. Before restart, the event log is reviewed by the microprocessor. If the event log contains a given number of vacuum anomaly events within a specific period of time, such as five minutes, then the controllers **48**, **148** shut down the circulation systems **10**, **110**. An alarm may be sounded via speaker **350** (see FIG. **10**B) and a message is displayed, such as on the displays **62**, **162**, or otherwise announced. The alarm may be silenced by depressing stop switches **76**, **176**, or will automatically turn off after a predetermined time period, such as 10 minutes. In order to restart the circulation systems **10**, **110**, the controllers **48**, **148**, respectively, require overt user intervention/action, such as responding to instructions/questions posed on the LCD or audibly over a speaker, by pressing combinations of the keys **64** and/or cycling the systems off and on. This same level of user interaction may be employed to prevent inadvertent running of the pumps **30**, **130** after a power failure.

[0048] The automatic reduction in vacuum level responsive to an excessive rate of vacuum change or excessively high vacuum levels (spikes) by venting the suction conduits **28**, **128**; or by permitting the accumulator **147** to release; and/or by turning the pump(s) **30**, **130**, **68** off, may be permanent in the case of a vacuum spike which is totally atypical (higher than L_D) and could only be caused by an anomaly, such as complete occlusion of a drain. In such instances, the system may be programmed to shut the pump(s) **30**, **130**, **68** down until an operator overtly resets the system, e.g., by going through a recovery procedure involving reading and responding to questions and instructions presented on the displays **62**, **162**.

[0049] In the situation where the vacuum release systems **39**, **139** operate at a more sensitive level, with vacuum change rate and level limits that are anticipated to be exceeded in the course of normal operation, then the controllers **48**, **148** may be programmed to automatically restart after a selected delay of, e.g., thirty seconds, for a given number of times until it shuts down permanently and needs to be overtly recovered. For example, if it is anticipated that the vacuum limits S_S, L_H will be exceeded between 3 and 4 times on start-up, then the controllers **48**, **148** can be set to automatically restart the circulation systems **10**, **110**, respectively, a given number of times, such as five or six times, before shutting down and requiring operator intervention to restart. This cycling through vacuum reduction, delay, and restart can be employed during any phase of operation. For example, during stable filtration, if a user places his/her foot on the drain causing the safe vacuum change rate S_S or high limit L_H to be exceeded, then the system may be programmed to reduce vacuum by venting or accumulator discharge, shutting the pumps **30**, **130** down for a few, e.g. three, seconds (during which time the user's foot is likely to have moved) and restarting. The variations of suction at the drains **12**, **14**, **112** are likely to remind the user that he/she is standing on a drain, thereby inducing him/her to move. If the condition persists, i.e., the partial blockage continues, the system can continue to try to restart for a given number of times, after which a shutdown requiring operator intervention will occur.

[0050] If a low limit L_L is utilized as a trigger to shut down the circulation systems **10**, **110**, then the time that the vacuum level is anticipated to be below that level, e.g., at the beginning of start-up, must be ignored. FIG. **8** illustrates a situation in which the lower limit L_L would be utilized to trigger a shut down of the pump(s) **30**, **130**. Namely, if, during stable filtration, the vacuum level drops below the low limit L_L, indicative of a broken line or disconnected fitting on the suction side of the pumps **30**, **130**, the controllers **48**, **148** can respond by shutting the pump(s) **30**, **130**, **68** off at time T_{OFF} to prevent their running dry, a condition that could lead to damage to the pump motor and seals.

[0051] FIG. **8** also shows the vacuum profile associated with an occlusion anomaly, e.g., as would occur during stable filtration when an object covers a drain, such as one of the drains **12**, **14**, **112**. At time T_{VR}, vacuum release and pump shut down occur, the dotted line showing the resultant vacuum profile and the solid line indicating the vacuum profile in the absence of the vacuum release systems **39**, **139**. As noted above, depending upon the level of L_H and user preferences, an automatic restart may be attempted after a delay, to allow time for the drain to be cleared.

[0052] FIGS. **10**A-**10**D and **11**A-**11**B each show a portion of an exemplary controller circuit **310**. FIG. **11** shows that the circuit **310** has a power input terminal block **312** to which the residential AC power supply would be attached. The 115, 230 or 208 VAC input voltage is converted to 24 VAC or 24 VDC for activating pump motor relays by a transformer **314**. A +5 DC voltage is produced by tapping the transformer **314** and passing 5 VAC through a rectifier **316**. This +5 DCV is used to power the various integrated circuits to be described below. Pump motors can be damaged by being connected to a power supply producing an incorrect voltage. A circuit **317** for sensing input AC voltage provides an output signal to a microprocessor **322** (FIGS. **10**A, **10**C and **10**D and depicted by the various input and output ports thereof in a plurality of separate boxes). If the voltage deviates from the required voltage by more than 10%, the power to the pump(s) **30**, **130**, **68** is disconnected. The sensing circuit **317** is calibrated at the factory to accurately measure the typical input voltages (115, 208 or 230 VAC). The microprocessor **322** is the main integrated circuit which receives the digital inputs created by the other circuit components, executes the control program, and also generates the outputs that control the vacuum release systems **39**, **139**. On FIG. **11**B, a vacuum sensor terminal **318** receives the voltage signal produced by the vacuum transducers **46**, **146** in contact with the suction conduits **28**, **128**, respectively. The vacuum signal is amplified and conditioned by a differential amplifier **320** and then provided to the microprocessor **322**. An LCD display **324**, e.g., a sixteen-character by two-line display, is utilized to display messages from the microprocessor **322** to the operator. A USB port **326** and a USB controller **328** allow data communication between the controller circuit **310** and another computer or data storage device (not shown), e.g., to program the microprocessor **322** or to read data stored in a memory **339**, as well as to download the historical events stored in the memory. Program updates can be input to the microprocessor **322** and to a non-volatile flash memory **327** through an IEEE connector and/or the USB port **326**. An event log is maintained by storage of data present at specific "events". The following are exemplary events that can be tracked and recorded in the event log: a feature change, such as, an adjustment to: the vacuum high limit, time limit to prime, rate of average change, pump turn on/off as directed by manual operation, programmatic timing and/or in response to safety or malfunction shutdown, entry/exit of pool technician mode, sensor and high spike calibration, time and date setting of the real time clock, automatic self-test with results, download of the event log, resetting of the event log (first entry in log), viewing the event log on the LCD, high or low AC power detected and system response, shut down and abnormal vacuum events including vacuum level detected and the applicable limits. The data associated with each event is stored in memory **339**, recording time, date, event code and information about the event, such as vacuum reading present at the time of the event. This data can be retrieved and reviewed at a later time, e.g., by a technician who connects a computer or hand-held device, such as a PDA, to the controllers **48**, **148** via the USB port **326**. The first entries in the event log may reflect manufacturing steps and test results for testing conducted at the factory. In addition to communication through the USB port **326**, the controller circuit **310** also includes an RS-485 transceiver **330** and bus **332** (FIG. **10**A) for connection to another pool/spa controller, such as the controller **65**, that has been previously installed on a pool/spa system. When so connected to the pool/spa systems S, S', the controllers **48**, **148** cede control to the existing pool/spa controller **65** with regard to timing the normal operation of the circulation system or parts thereof, but retain control of vacuum level monitoring of the suction conduits **28**, **128**, the vent valves **42**, **44** and/or the accumulator valve **155**, while also retaining the ability to turn the pumps **30**, **130**, **68** off in case of an anomaly. This coordination with an existing controller is accomplished programmatically in the microprocessor **322**.

[0053] A battery **334** driven oscillator **336** feeds a real-time clock **338** to provide a time reference for conducting programmed/scheduled activities, such as pumping/filtration at various speeds, for timing windows of permissible vacuum levels during pump priming and speed change and for time-stamping events recorded in an event log of events that is stored in memory **327** and/or non-volatile flash memory **339**. It is preferable for the flash memory **339** to be able to store at least a thousand of the most recent events. Back-up power to the flash memory **339** is provided for the real-time clock **338** by a super capacitor **341**. A programmable timer **340** is provided to time events relative to the actual time and has the capacity to schedule, e.g., one to five, separate daily events each day for a week, or the same separate daily events repeated each day.

[0054] Three momentary switches **342** are provided to permit the user to enter data into the controllers **48**, **148**. More particularly, the switch buttons may be labeled "Up & Yes", "Down & No" and "Menu & O.K. & Test" and can be used to enter answers to questions posed on the display **324**, as well as to incrementally change values for date, time and vacuum limits, etc. An LED **344** (FIG. **11**B) indicates that the system is powered and an LED **346** indicates when a high-temperature condition is sensed by temperature sensor/thermal switch **347**, viz., if the system senses a temperature in excess of 70 degrees C. in the controller box, this LED **346** illuminates and the display **324** is shut down to prevent damage from overheating. The illuminated LED **346** indicates that the system is still active even though the display is blank. DIP switches **348** may be used to select the language that the microprocessor displays on the display, **324**, e.g., the input voltage, the number of pumps, whether a controller is present, etc.

[0055] The controller circuit **310** and connections thereto may be housed in a wall-mounted enclosure made from metal and having a grounding lug to which a connection to earth ground is made. The housing may be compartmentalized to contain the high voltage components in one section separate from the low voltage components which are housed in a separate compartment separated by a conductive barrier that is in electrical continuity with the grounded metal housing. In this manner, the high voltages present in the high voltage compartment are prevented from inadvertently contacting low voltage components contained in the other compartment. The high voltage components may be positioned toward the bottom of the housing with the connector terminals pointed downwards to receive the high voltage power lines inserted into the housing from the bottom. The metal housing may be further protected by a clear plastic outer housing which may be hingedly connected to the metal housing to shield the unit from the weather while permitting an operator to view the LCD displays **62**, **162** and the LED's **344**, **346**. During manufacture, the individual circuit components of the controller circuit **310** are tested as they are installed to debug and isolate defective parts. Upon completion of the assembly, the circuit is powered up for a significant time and then tested multiple times to assure proper operation. Having passed assembly and operational testing in the factory, the controller(s) **48**, **148** may then be installed at a user's site by an installer/pool technician.

[0056] Installation/Setup by Technician

[0057] In preparation for installing the present invention in an existing pool/spa/system, any existing check valves are removed from the suction lines, e.g., suction lines **18**, **28**. Check valves are frequently used to allow pumps, such as the pump **30**, that are installed above the water level of the pool/spa to maintain prime after the pump has been turned off. In order for the present system to work effectively, check valves must be removed that would impede venting the suction conduit **28** to atmosphere or delivering a pressurized back flow of water from the accumulator **147**. Before connecting electrical power to the system, the housings of the controller **48**, **148** would be opened to access the DIP switches **348**, which are set to indicate language preference, to indicate whether there is a one or two speed pump, the input voltage for the controller (selected by switch S1 on the PCB board) and other voltage loads, to indicate if a booster pump, such as the pump **68**, is present in the system and to indicate whether the vacuum release systems **39**, **139** will control the running of the pump (s) **30**, **130**, **68** on a time schedule or schedules, as applicable, etc. In order to connect the controllers **48**, **148** to the power supplies **54**, **154**, respectively, to the vacuum sensor/transducers **46**, **146** and to the pumps **30**, **130**, **68**, the panel protecting the high voltage terminals in the controller housing is removed. The technician can then connect: (1) a remote stop switch, which is normally closed in "run" mode; (2) the terminal pair for a remote alarm relay (normally open—115 volts @5 Amps); a plurality of terminal pairs to pump motor relays (contactors); and the AC power source (115, 208 or 230 VAC). The power cables to the one or two speed pumps **30**, **130** and optional booster pump **68** are connected to AC contactor terminals, routed through the bottom of the housing and connected to the respective pump motors. The pump motors are typically rated at up to 1.5 hp at 115 volts or 3 hp at 208 or 230 volts. In the event that a higher power pump is utilized, the contactors can be used in series with the pump motor starters. Each of the motor contactors is controlled by a separate I/O pin of the microprocessor **322**. The housings of the controllers **48**, **148** are grounded to the electric supply circuit breaker/fuse boxes **54**, **154**, respectively and also to the bonding system for the pool/spa, if available. The housings can then be reassembled and power to the systems **39**, **139** can be turned on. The voltage sensing function of the system is immediately operative and will confirm that suitable voltage is present to power the controllers **48**, **148**, the solenoid valves **42**, **44**, **155** and the pumps **30**, **130**, **68** via a message displayed on the displays **62**, **162**, respectively.

[0058] The controllers **48**, **148** have different access classifications, viz., manufacturer, installer/technician and consumer, which allow successively more limited access to controller settings and values. Some settings are accessible to the owner/operator and some are reserved for installer/technicians and factory technicians. Each controller is set for user access when it leaves the factory. Access by technicians can be password protected or require a proprietary sequence of momentary switch depressions or the like.

[0059] Having gained access, the technician can then communicate commands and settings to the microprocessor **322** by depressing the momentary switches **342** in conjunction with and in response to the display of prompts from the microprocessor **322** displayed on, for example, the displays **62**, **162**. The technician can set the initial parameters for the particular installation, including: the value corresponding to a default high vacuum spike criteria L_D which would indicate an occlusion; the value for ultra-safe vacuum level L_H during filtration; and the delay before restart is attempted. The priming time criteria may also be set/calculated at this point. In appropriate cases, the installing technician will exercise all of the pool and spa functions, such as, priming, filtering, speed changes, etc., and observe and record the timing and vacuum levels associated with those functional states. Alternatively, the controllers **48**, **148** can automatically capture this data as the circulation systems **10**, **110** are exercised. The technician may exercise these systems by following written instructions or by following cues displayed on the displays **62**, **162**. The technician would then exit custom set-up mode and enable pump protection from abnormal AC voltages. A data display mode would then be entered which dynamically displays operational parameters based upon sensed empirical sensor readings/values, such a vacuum readings in the suction conduit **28**. These are typically expressed in inches of mercury.

[0060] Besides controller setup, the technician can perform certain maintenance tasks, as well as all the user functions that are available in user mode. The controllers **48**, **148** automatically shut down pump operation when technician mode is entered. One of the special functions available only in technician mode is to override shutdown due to excessively high vacuum readings. This shutdown override is sometimes necessary to clear obstructions, such as leaves, that may at times clog the drains **12**, **14**, **112** that could not otherwise be conveniently removed. Of course, during override, the technician must be certain that the pool/spa is not being used by any persons.

[0061] User Preference Selection—Setup/Maintenance

[0062] The user can perform the following at any time via the operator interface (input keys **64** and display **62**): initiate a self-test; set the real-time clock **338**, and schedule events to be executed in the future programmatically, such as the schedule of pump operation, viz., times for turning the pumps **30**, **130** on and off, for running them at high and low speed and for turning the booster pump **68** on and off for cleaning purposes.

The technician can also view the most recent events that have been logged into the event log and step back sequentially to view prior events. The user can review the recorded log of errors that have occurred and respond to any questions posed by the controller **48**, **148**. Responding to certain questions may be required before the controller will permit access to certain functions or effecting selected settings.

[0063] FIG. **12** shows a vacuum release system **400** with a controller **410** that controls the electric power delivered to pump **412**. As in previous embodiments described above, electrical power is provided on power supply line **414** which passes through a circuit breaker box **416** and to the controller **410** which then powers and depowers the pump **412** via line **418**. As before, the pump **412** is used to draw water from a pool or spa (see FIG. **1**), which is then routed through a filter via return line **428** before returning to the pool/spa. Water is routed through main drain valve **420** and/or skimmer valve **422** to a suction conduit **424** and into a strainer **426** that removes debris in the water. A vacuum conduit **430**, e.g., copper or plastic tubing, extends between the suction conduit to the controller **410**. A vent **432** is provided on the controller to allow air to enter the vacuum conduit **430** and the suction conduit **424** to reduce the vacuum present therein, as controlled by a solenoid valve **458**. More particularly, the solenoid valve **458** has at least two positions: i.) a first establishing fluid (vacuum) continuity between vacuum conduit **430** and conduit **462** leading to vacuum sensor **435**; and ii.) a second establishing continuity between vacuum conduit **430** and conduit **464** leading to vent **432** to atmosphere. As noted above, vacuum sensor **435** may be of the piezoelectric or diaphragm type, e.g., Model No. 22PCCFB6G, manufactured by Honeywell. The electrical output of the vacuum sensor **435** (change in resistance, voltage or current) is conveyed to the microprocessor **437** (see also **322** in FIGS. **10**A, **10**C and **10**D) to indicate the vacuum level in vacuum conduit **430**. A visual (light) and/or audible alarm **427** (bell, buzzer, speaker, etc.) may be used to announce an emergency condition. A kill/stop switch/panic button **429** is wired to the controller **410** to permit the operator to turn the pump(s) off and release vacuum in the suction conduit **424** (and attached drains). A spare switch **431** may be employed to override controller **410** operation of a pump or pumps, for example, to turn the filtration pump on HIGH and/or to turn the booster pump ON for cleaning the pool out of the predetermined schedule of operation.

[0064] FIG. **13** shows a vacuum release system **500** with a controller **510** that controls the electric power delivered to pump **512**. As in previous embodiments described above, electrical power is provided on power supply line **514** which passes through a circuit breaker box **516** and to the controller **510** which then powers and depowers the pump **512** via line **518**. As before, the pump **512** is used to draw water from a pool or spa (see FIG. **1**) which is then routed through a filter via return line **528** before returning to the pool/spa. Water is typically routed through main drain valve **520** and/or skimmer valve **522** to a suction conduit **524** and into a strainer **526** that removes debris in the water. A vacuum conduit **530**, e.g., copper or plastic tubing, extends between the suction conduit to the controller **510**. The solenoid valve, vacuum sensor, associated conduits, and microprocessor are the same in the embodiment shown in FIG. **12**, so for simplicity of illustration are not redepicted in FIG. **13**. A fitting **533** is provided on the controller **510** to couple a reverse flow conduit **535** thereto. An accumulator **537** has an outlet fitting **539** to which the reverse flow conduit **535** attaches. A check valve **541** is connected to another branch of the outlet fitting **539** and receives an end of pressurized fluid conduit **543** which fluidly communicates with outlet line **528**. Fluid under pressure of the pump **528** courses through conduit **543**, through check valve **541** and into the accumulator **537** during normal filtration. The energy of the pressurized fluid is stored in the accumulator **537** via a resilient member, such as a spring acting against a piston or a pocket of gas, such as air in a bladder. Fluid flow into the accumulator ceases when an equilibrium between the pressure of the fluid and the resilient member is established. Once past the check valve **541**, the fluid under pressure is trapped within the accumulator **537** and the conduit **535** until it is released into the suction line **524** via the vacuum conduit **530** and a solenoid valve **458** (See FIG. **15**) contained within the controller **510**. This pressurized fluid can be used to reduce vacuum pressure present in the suction conduit, e.g., attributable to a person being trapped on a drain, as shall be explained further below. The embodiment shown in FIG. **13** reduces the vacuum present in suction conduit **524** by a reverse flow of pressurized fluid from the accumulator **537**, rather than by venting the suction conduit **524** to atmospheric air as in the embodiment shown in FIG. **12**. This type of vacuum reduction mechanism is especially appropriate for above-ground pools/spas where the water level is above that of the pump/strainer, also described as an installation with “flooded suction”. The embodiments of the present invention shown in FIG. **13** may incorporate a kill switch **429**, spare switch **431** and alarm **427**, as shown in FIG. **12**. Similarly, any of the embodiments disclosed herein, for example, in FIGS. **1**, **2**, **12** and **13** may include the features shown in another of the embodiments, such as booster pump **68**, accumulators **537**, spare switches **431**, etc.

[0065] FIG. **14** shows the controller **410** with the access door **438** of the housing **436** open, revealing decals **440** with instructions for wiring the controller **410** and the inner panel **442**, which shields pool/spa owners from contacting the interior circuitry of the controller **410** to prevent shocks. The inner panel **442** also frames and bears indicia for indicating the identity/function of operator interface components, such as the display, **444**, three control buttons **446** (YES/UP), **448** (NO/DOWN) and **450** (MENU/OK), a power indicator **452** and a display/reboot indicator light **454**. The vent **432** incorporates a filter element **434**, which may be made of conventional filter materials, such a sintered brass, metal gauze, paper, etc. The filter **434** prevents debris from entering the vent **432** and also prevents the vent from becoming occluded resulting in interrupted or diminished functioning. Bonding lugs **456** are provided on the housing **438** to receive grounding wires (not shown).

[0066] FIG. **15** shows the controller **410** with the inner panel **442** removed, revealing solenoid valve **458** which controls the fluid (vacuum/air/water) communication of conduits **460**, **462** and **464**. Printed circuit board **466** includes the display **444**, the buttons **446**, **448** and **450** terminals **467** and input voltage selector **469**. A pump terminal block **468** and a grounding lug **470** are positioned below the circuit board **466**.

[0067] In FIGS. **16**A and **16**B, a diagram **472** shows exemplary terminal assignments. Diagram **474** illustrates exemplary wiring for electrical input power terminals to power a filter pump and a booster pump. Diagram **476** illustrates exemplary wiring connections to power a booster pump and a two-speed filter pump. Diagram **478** illustrates the terminal connections for powering a single speed pump. Diagram **480** illustrates the wiring connections for powering a three-phase pump.

[0068] FIG. **17** shows an accumulator **537** having a generally cylindrical body **545** closed at one end by a top cover, which may be secured to the body **545** by threads and/or other retaining means, such as a clamp band. A piston **549** having an o-ring seal **551** is coaxially received within the accumulator **537** and is urged away from the cover **547** by a spring **555**. A spring guide **557** has a pointed end **558** that fits within a complementarily shaped depression **560** in the cover, with the other end inserting into the spring **555** to center the spring **555** relative to the cover **547**. A depression **562** is provided in the piston **549** to center the spring **555** relative thereto. The body **545** of the accumulator **537** is closed at the end opposite to the cover by a plug **559**. A threaded opening **553** passes through the body **545** proximate the plug **559** to admit fluid under pressure into the accumulator to displace the piston **549** towards the cover **547**, compressing the spring **555**. The threads in the opening **553** may be used to secure a fitting like outlet fitting **539** in fluid-tight relationship to the accumulator **537**.

[0069] FIG. **18** shows a line tapping kit **600** for connecting tubing **610** (e.g., for use as a vacuum line, e.g., **530** and/or pressurized fluid line, e.g., **543**) to a conduit **614**, such as the suction conduit **524**. The conduit **614** is drilled and a tap fitting **616** is inserted in the drilled hole **620** with a gasket **618** there between. A clamp **622** pushes the tap fitting **616** into the hole **620** when the clamp **622** is tightened, the tap fitting **616** inserting into a hole **623** in the clamp **622**. A ferrule nut **612** disposed on an end of the tubing **610** may then be threaded onto the tap fitting **616** to make a fluid-tight connection.

[0070] FIGS. **19***a-f* show a flow chart **700** of the operation of an exemplary embodiment of the present invention. The system, e.g., **400** or **500**, including the controller thereof **410**, **510** is powered ON **710**. (For purposes of simplicity of illustration, the system **400** will be referred to in describing the functionality expressed in the flowchart **700**. It should be understood that any of the embodiments disclosed herein could utilize this same functionality.) The controller **410** may be powered ON in different contexts, e.g., after manufacture for testing, in the course of installing the system at a residence, by the owner of a pool/spa to input his/her preferences for operating the pool/spa, by the owner during maintenance, for first use of his pool/spa after being shutdown, for maintenance by the owner, by technicians, etc. The context in which the controller **410** is powered ON **710** is determined by operator input, switch settings, and/or states in the system **400** that indicate the context. After power is applied, the controller **410** (programmatically in the microprocessor, e.g., **322**) conducts an internal test **712** to determine if "initial start is enabled". This state is initialized to the negative, i.e., the system does not start immediately upon turning the power ON **700**, to provide the operator with control over the system **400**, i.e., to send power to the pumps, e.g., **412**, etc. only when the operator has determined that he/she is ready and it is safe to do so. The operator is queried **714**, "Initial Start Now?". If any other key is pressed or if no key is pressed in response, then the controller will idle indefinitely without applying power to the pumps (starting). If the "Y" key is depressed to indicate "Yes", then the operator is queried **718**, "Disable Start Delay?". If the "Y" key is depressed within a given opportunity time, e.g., five seconds, then the initial start delay is disabled (by setting an internal flag or variable value). The consequence of disabling the start delay will be that system **400** will immediately implement controlled functioning upon applying power **700** to the controller **410** in the future.

[0071] At step **726**, the controller **410** internally checks to see if DIP switch **5** is "ON" to indicate that the context of powering up **710** is in the manufacturing environment, e.g., pursuant to testing the functioning of the controller **410**. If so, then such testing is conducted **728**. The manufacturing tests would involve applying inputs to the controller **410** and ascertaining that the controller responds with the correct outputs/responses. For example, known vacuum levels may be applied to the controller (through the solenoid valve to the vacuum sensor) to see if the controller responds appropriately thereto, e.g., shutting off power to the pump when the vacuum level exceeds a preselected threshold, as shall be described further below and as previously described above. Similarly, the power supply can be varied, e.g., via a vacuum to ascertain that the controller **410** responds appropriately to such variations, e.g., responding to a low power condition with the appropriate warning messages and shutting power to the pump off. The controller **410** can also be checked to confirm that it outputs the proper messages making up the operator interface and responds appropriately to operator input.

[0072] In the event that the manufacturing context is not applicable at step **726**, then the controller (via the display **444** thereof) displays **730** the message "Hayward Pool Products, Inc." or similar introductory messages identifying the manufacturer or otherwise communicating with the operator. This is followed by displaying **732** the date and time. In the eventuality **734** that the operator wishes to clean the pool/spa e.g., by using a pool vacuum, the operator can so signify by simultaneously pressing the "Menu" and "N" keys. Note that checking **734** whether the operator wants to clean the pool or not is not necessarily a overt query posed to the operator via the display **444**, but rather is initiated by the operator pressing an improbable combination of keys on the operator interface to indicate that cleaning the pool is desired. In this manner, inadvertent selection of this option is avoided and the selection may be made only by someone who has learned how to operate the controller, e.g., by reading the manual or by receiving operating instructions from a technician or other knowledgeable person. In the event that the operator of the pool/spa (be that the owner, a technician or installer) indicates that they want to clean the pool/spa, the Clean Pool Function is invoked **736**. The Clean Pool Function allows the pump, e.g., **412**, to be operated at high speed and also allows the booster pump, e.g., **68** to be operated without monitoring the vacuum level. This is permitted because the process of vacuuming/cleaning may cause the vacuum level to spike in the normal course thereof. In order to permit vacuuming/cleaning of the pool/spa, vacuum monitoring must be overridden for a time. Before entering this unmonitored mode, the operator is warned **738** on the display **444** that the pump is about to be operated in unprotected (no vacuum monitoring) mode and that the pool must be cleared of all persons. The controller then queries the operator **740** to determine if the pool has been cleared. If the answer is "Yes", unmonitored operation of the pump **742** is performed. Pool cleaning mode will not begin until the operator indicates the pool is cleared of swimmers. Upon such indication, unmonitored operation persists for a given time, whereupon unmonitored operation comes to an end based upon the expiration of a predetermined time window, e.g., a given number of minutes, which can be determined by factory set defaults, or alternatively, this may be a variable set by the installer or the pool owner upon installation/reinstallation. As with operation of the controller **410** generally, all operational states are recorded in an operational log (in non-volatile memory or media).

[0073] Assuming that cleaning mode has been skipped or completed, the controller **410** then queries **744** if the operator wishes to set the Time and Date. If so, the Time and Date functions **746** are executed, which are conventional, such as would be encountered in setting the time and date on any modern appliance or clock. The controller then ascertains if Timer event setting has been enabled (by setting DIP switch **4** "On" previously, e.g., during installation. If so, the operator is queried **748** if they want to Set Timer Events. If the operator indicates "Yes", the Timer Events Function is invoked **750**. The Timer Events are used to control the ON and OFF times of the filter pump, e.g., **30**, the booster pump, e.g., **68**, and the high and low settings of two-speed pumps, e.g., **30**. The timed events may be scheduled for daily execution (every day of the week has the same schedule of events) or each day of the week can be assigned a custom schedule, which may or may not be the same as another day of the week, e.g., to accommodate the individual's preferences and schedule of usage of the pool/spa. DIP switch, flags or other variable settings with values assigned on set-up or installation can be used to indicate the presence of two speed pumps and/or booster pumps in the system. Alternatively, the controller can sense on the wiring connections thereto to ascertain the presence of specific equipment configurations. The Set Timer Events Function **750** steps through each device to ascertain from operator input when the devices should be turned ON and OFF each day of the week.

[0074] After the Timer Events query **748** and/or execution of the Set Timer Events Function **750**, the controller checks to ascertain if the operator wishes to enter pool tech mode **752**. This indication from the operator is not in response to a query posed by the controller, rather, the checking is done without messaging the operator via the display, e.g., **444**. More particularly, if the operator, of his own incentive, wishes to enter Pool Tech Mode and is aware of the combination of key depressions that are required, then Pool Tech Mode may be so indicated. It should be appreciated that any improbable combination of key depressions may be used as a secret code to invoke certain functions and that the secret code can be shared with a limited number of qualified persons to prevent unqualified persons from accessing certain functions that could otherwise be conducted. In FIG. **19***b*, the combination of key depressions is to double click the "OK" key. Of course, other combinations could readily be employed for this access "code". If Pool Tech Mode is successfully invoked, the Custom Installation Functions **754** and the Pool Tech Mode Functions **756** can be then be selected and performed. Custom Installation Functions would typically be conducted on initial installation of the system **400**, however could be invoked later to reinstall the system or to make modifications to the original settings. Pool Tech Mode would include observing the measured vacuum sensed while the pool/spa is running in various modes, e.g., on start-up (while priming), while filtering, when running on high and low pump speed settings, when the booster pump is running and when cleaning (vacuuming the pool/spa). This gives the technician the opportunity to observe the actual vacuum levels actually realized during normal operation in these modes. The technician is then given the opportunity to change the high vacuum setting, i.e., the setting that will trigger shutdown. The system **400** preferably is initialized to have a default high vacuum setting, e.g., 12" Hg. If the pool/spa is operated in a mode typically having the highest vacuum levels, then the high setting can be assessed against actual levels encountered in this mode of running. For example, many pools experience high vacuum levels when the suction outlets are partially closed and a suction pump is in the skimmer. Based upon the actual vacuum readings, the high vacuum (fault trigger) setting can be adjusted upwards, e.g., in increments of 1" Hg. The maximum setting should never exceed 5" Hg. above the vacuum level needed to run the pool cleaner/vacuum. Another, alternative method for establishing the high vacuum limit, is to set the vacuum at a very high level, e.g., 20" Hg. to permit operation and then to reduce the level to 5" Hg. above the empirical vacuum level experienced when the pool is running in a stabilized condition.

[0075] Another Custom Installation function is to zero the vacuum sensor. The sensor is initialized to zero at the factory and therefore reflects a zero value for the specific atmospheric pressure at the factory. In the event the system **400** is installed at a significantly different elevation, then the difference in atmospheric pressure or due to the static pressure of the water when the pump sensor is below the water level, may result in pressure effects attributable thereto rather than directly attributable to operation in a pool spa system. Accordingly, the present invention permits re-zeroing the vacuum sensor. The power supply voltage level (115/208/230 VAC) may also be set.

[0076] Because the time required for priming the pump will vary for the particular installation, e.g., due to the length of the suction conduit **424** and/or the other lines leading from the drains and the elevation of the pump relative to the water level, the controller **410** during Custom Installation Functions **754** permits the amount of time allocated to achieve prime to be adjusted during the custom install procedure. In addition to adjusting the time allotted to prime the pump before indicating an error condition, the threshold vacuum value used to ascertain if priming is occurring without a critical defect in the lines (break in the line which admits air or other water/air leak, such as an improperly installed strainer lid, that would lead to dry running of the pump) may also be adjusted. Once again, because the vacuum levels experienced during priming will vary for specific installations, normal priming vacuum levels for one installation may be significantly higher or lower than for other installations, hence the threshold indicating critical failure needs to be adjusted up or down based upon empirical values observed by the technician. The default vacuum threshold for priming is initially set to 30% of the vacuum level observed during stabilized operation of the circulation system. Unless the particular installation experiences difficulty in priming, the 30% default value should not be changed. Further, because an acceptable time for priming will also vary among different systems, the priming time criteria may also be based upon empirical measurements of same, either by the technician or automatically by the controller. As described more fully above, the controller may expand the time and update the priming time criteria based upon observed priming times.

[0077] Given that the vacuum conditions during stable running will change depending upon changing conditions within the filter (as the filter accumulates dirt, it will present more resistance to the filtration flow resulting in lower vacuum values.) A stable running low threshold is therefore useful to provide a window of operability without indicating an error condition that triggers shutdown of the circulation system. As noted above, in addition to monitoring for high vacuum conditions indicating blockage of a drain, the controller **410** also monitors for low vacuum conditions which could indicate a line break such that the pump(s) may be protected from run-dry conditions by depowering the pump. This low vacuum monitoring uses values appropriate to the stage of operation that the system is in, e.g., priming or stable running. In stable running, the low vacuum threshold is set by default at 60% of the normal, unimpeded stable running vacuum level. As noted above, because each pool/spa installation will vary, e.g., in the type of filter employed, i.e., DE, sand, cartridge, the size of the filter, the amount of debris loading due to environmental effects, the stable running low threshold may need to be adjusted. This can be done as part of the Custom Install Functions **754** based upon the vacuum levels noted empirically (by the installation technician or a trouble shooter who has come to resolve the frequent shut-down of the system).

[0078] When the system is first installed and the pump is run, the controller, e.g., **410** recognizes when the pump **412** achieves a stable condition and records the vacuum level associated with that stable run condition. In the event that the first recorded stable run vacuum level was not representative of the actual stable running, e.g., due to an anomaly, such as an air leak due to an improperly installed strainer basket lid, then the Custom Installation Functions permit the technician to reset the stable vacuum level after the correction of the condition leading to the anomaly.

[0079] If the operator pressed "Y" in response to query **752**, then the Pool Tech Mode Functions **756** are enabled. The time and date are displayed **758**. If Pool Tech Mode was selected at decision **752** and the controller **410** is in Active Pool Tech Mode **760**, the Pool Tech Mode functions are presented to the operator via specific messages **762**. These messages and functions would include a query to the operator as to whether a two-speed pump is installed and if so, to double check that the dip switch settings are appropriate for a two speed pump. The operator is then queried if the drain cover(s) are installed. If not, the system must be powered down before it will restart. If the drain cover(s) are installed, the operator is queried as to whether he/she would like to manipulate the data log, which is a log of all events retained in the memory of the controller. The event log can be used by the technician to identify and correct problems in the system. After completing the desired Custom Installation Functions and/or the Pool Tech Mode Functions, such as setting the high vacuum level, the operator may terminate Pool Tech mode by pressing "OK/MENU".

[0080] On FIG. **19***c*, the processing continues with an internal check **764** to ascertain if the timer has been enabled. If so, the program checks **766** to see if a spare switch is ON. A spare switch is a physical switch that the pool/spa owner or a technician can use to turn a pump associated therewith ON (overriding the OFF state otherwise established by the controller **410**, e.g., pursuant to a schedule/timed event). Preferably, the spare switch is a logical switch which is connected to the microprocessor of the controller **410**., rather than a power switch which directly controls power to the relevant pump. If the Spare Switch Is ON, then the microprocessor is instructed to Set Spare Switch Operations **768**, e.g., turn the filter pump and/or the booster pump ON in order to clean the pool.

[0081] If the test **766** is Negative, then the controller **410** checks **770** if the timer indicates a RUN condition/If not, messages pertaining to time scheduled events are displayed **772**, such as, identifying the next timed event and when it is to occur, as well as indicating to the operator that they may press MENU for other options. The controller **410** monitors if MENU has been pressed **774**. If so, control returns to connection point "A" on FIG. **19***a*. If MENU is not pressed, control loops back through decision **766** until the spare switch is turned ON, the timer indicates RUN or the MENU key is pressed.

[0082] When the timer indicates RUN at decision **770**, an AC Voltage test is conducted **776** wherein the controller **410** ascertains whether the voltage level is within an operable range, i.e., not too high due to a surge or too low due to a brown-out or other power interruption. If the voltage is out of range as tested at decision **778**, control passes to connection point "E" on FIG. **19***e*. If the voltage is within range, the controller proceeds to the Pulsing and Priming Functions **780**, i.e., to start the filtration pump **412**. On startup, the vacuum solenoid valve **458** is opened and closed several times to "soft start" the system and to warn swimmers that the pump **412** has started. A self-test may be conducted at this time to verify that the vacuum sensor **435** and solenoid valve **458** are functioning properly. More particularly, when the pump, e.g., **412** is cycled ON/OFF, or the vacuum solenoid valve **458** is opened, there should be corresponding changes in vacuum levels, which should be sensed by the vacuum sensor **435**. If vacuum sensor **435** functionality is compromised due to a blocked line, e.g., **430** or **462**, or a failure of the pump **412** to respond to control signals that would generate a vacuum variation, this anomaly is recorded in the log and error processing proceeds at connector "E" on FIG. **19***e*.

[0083] In addition, before power is applied to a pump, e.g., **412**, the vacuum level present in the suction conduit **424** is checked. Depending upon how many pumps are installed in the pool/spa system and how many are running, a specific pre-running vacuum level can be expected. For example, in the case of pool with a single pump **412**, the pre-running vacuum level should be nil. If the pre-running vacuum level is not at the expected level, e.g., in a pool with one pump **412**, if the vacuum level is greater than nil, then this may be interpreted as an indication that the pump **412** is already unexpectedly running. If the pump **412** is unexpectedly running, then this is likely an indication that some portion of the system that controls the running of the pump **412** is malfunctioning. One example of a malfunction which would cause unexpected pump running would be a motor contactor (relay) which is stuck in the "ON" position, e.g., due to the welding of the contacts (points) thereof. In the event that an unexpected vacuum value is detected which is attributable to an unexpectedly running pump, then this anomaly is recorded and error processing is invoked starting at connector "E" in FIG. **19***e*.

[0084] During start-up, the controller continually tests **782** to verify that the high vacuum limit is not exceeded, which would indicate a malfunction, such as the occlusion of a drain, thus protecting swimmers from becoming trapped on a drain. A low vacuum threshold is also optionally tested at this time, as set at step **754**, to prevent the pump **412** from running in a dry state. In addition to monitoring vacuum levels, the time to achieve prime condition may also be monitored and compared to the priming time criteria. If errors are encountered, the nature of the error is recorded and error processing is continued at connector "E" in FIG. **19***e*. If prime is achieved, the priming time criteria may optionally be adjusted.

[0085] If no errors are encountered, the Stabilization Function **784** is performed. While the pump **412** is running, the vacuum sensor **435** continually monitors the vacuum level reporting it to the controller **410** and the controller **410** continually verifies **786** that the High Vacuum Limit is not exceeded. As the pump **412** becomes fully primed, the vacuum experienced by the vacuum sensor **435** should stabilize. This stabilization allows Vacuum Window Parameters to be set **788**. The Vacuum Window is a tolerance range of vacuum variation centered around the actual experienced vacuum level empirically determined at stabilization. Given this empirical value, the vacuum window may then be set to be in a range (+/−) of this actual reading (average reading), e.g., +/−3" Hg. As a result, the Vacuum window is a tighter range of acceptable vacuum levels than that between the High and Low Vacuum Limits and is centered on the actual operating vacuum levels present in the running pool/spa system after stabilization.

[0086] Optionally, the present invention may continually adjust the Vacuum Window in a manner similar to the way the priming time criteria is interactively adjusted based upon sensed empirical data, e.g., to compensate for changing conditions in the system S, S', such as a filter **34** that provides changing resistance to fluid flow due to debris accumulation/removal and therefore results in changing levels of vacuum for associated operational states. More particularly, the Vacuum Window may be adjusted upward and downward based upon the measured vacuum for any operational state. For example, if the vacuum during stabilized running in filtration mode is empirically measured to be X on a newly installed system and expanded by a tolerance of +/−3" Hg, resulting in a Vacuum Window of X+/−3"Hg, then measured to be X-1"Hg on a subsequent cycle in the same operational mode, the controller **48**, **148** would interpret that the measured vacuum level X-1" Hg falls within the acceptable range of X+/−3" Hg. However, because the measured vacuum level is 1" Hg less than the previously measured level, the controller may recalculate the vacuum window to be (X-1" Hg)+/−3" Hg. These incremental changes can be utilized to move the vacuum window to accommodate expected changes in function of the system S, S'. The adjustment in the vacuum window implies, however, that a maximum and minimum should be established beyond which no incrementation/decrementation can be permitted.

[0087] Having established the Vacuum Window Parameters **788**, the controller **410** then executes Run Mode **790**. When the system is in Run Mode **790**, vacuum measurements are taken at about 1000 samples per second and averaged, yielding a test vacuum value every hundredth of a second. This average value may then be compared **794** to the vacuum window calculated in step **788** to determine if it is within an acceptable range. If not, vacuum anomaly processing is conducted (connector “E”). Besides monitoring vacuum levels, the power input voltage is also monitored **792** to ascertain if it remains in an acceptable range. If not, error processing is conducted (see connector “E”).

[0088] The operation of the spare switch, e.g., **431** (if applicable) is also monitored. In the event that a spare switch **431** has been operated (decision **796**), the state of the spare switch is tested **798**, i.e., to see if it is presently OFF. If the spare switch is OFF, the controller records that state (Reset Spare Switch Operation **800**) and turns the pump(s) controlled by the spare switch OFF **810**. When the pumps. e.g. **412**, are turned OFF, a corresponding reduction in vacuum should result. If not, then this would be an indicator of loss of control over the running of the pump **412**, e.g., due to a malfunctioning contactor (relay) as in the case of welded contact points. The systems therefore tests the vacuum level **811** to verify vacuum reduction due to pump shut-down. If the expected change in vacuum levels does not occur, then this error is recorded and control is passed to connector “E” in FIG. **19***e*. In the event that the spare switch is ON, the controller **410** continues to run the pump(s) effected. The controller **410** checks a time count **820** to determine if it is time to conduct a vacuum sensor and solenoid test. Periodically, e.g., every 6 hours, the vacuum sensor **435** and solenoid valve **458** are tested **822**, i.e., by exercising them through a variation in pumping, e.g., by cycling the vacuum solenoid valve **458** and/or the pump **412** to ascertain that the vacuum changes and is sensed. For example, if during pulsing (step **780**), if a difference of at least ½" Hg. between the highest and lowest measured vacuum levels is not detected, then the sensor/solenoid test is failed. If the vacuum solenoid valve **458** and vacuum sensor **435** pass the test, then processing continues at connector “C” otherwise error processing proceeds at connector “E” on FIG. **19***e*.

[0089] For embodiments of the present invention utilizing a vacuum conduit, such as **430** that extends to the controller **410** and to a vacuum sensor **435** therein, the present invention preferably includes a vacuum monitoring function that verifies that the vacuum conduit **430** is not plugged with debris or kinked and therefore obscuring the actual state of vacuum present in the suction conduit **424**. More particularly, vacuum levels established in vacuum conduit **430** and vacuum tube **462** are sensed by vacuum sensor **435**. These levels change depending upon the state of the pump **412**, the obstruction of drains, e.g., **112**, etc. In addition, there are small fluctuations in the vacuum level that are present even after stabilization. If the vacuum conduit becomes obstructed, e.g., plugged with debris or kinked, then the portion of the vacuum conduit **430** between the obstruction and the vacuum sensor **435** becomes sealed/isolated from the vacuum levels present in the suction conduit **424**. As a result, the sealed/isolated portion of the vacuum conduit **430** will retain the vacuum level that was present therein when the obstruction occurred and therefore the sensor will not be effective in detecting changing vacuum conditions in the suction conduit **424**. Of course, this type of occlusion would frustrate the operation and purpose of the vacuum release system **400**.

[0090] In order to detect and prevent any negative consequences from vacuum conduit **430** occlusion, the present invention monitors the vacuum level for a sustained, unchanging vacuum level, i.e., a static vacuum level, which would be indicative of vacuum conduit **430** occlusion. A static or constant vacuum level would be indicative of occlusion because even in stabilized running, there is a constant fluctuation in vacuum level during normal operation. The present invention therefore compares the vacuum level taken at successive intervals and ascertains if there is an abnormal constancy. If the vacuum level appears static, then the vent valve **458** is triggered exposing the vacuum conduit **430** to atmospheric pressure or to the pressure developed in the accumulator **537**. In addition, the pump **412** may be cycled ON/OFF. These action(s) are intended to purge the vacuum conduit **430** of clogs. Upon sensing abnormal constancy in the vacuum conduit **430** and triggering the vacuum reduction response, the error event is recorded. The system **400** then resets the vent valve **458** to a non-venting position and/or restarts the pump **412**. Vacuum level is rechecked to ascertain normal fluctuations in vacuum. If the vacuum remains constant, error processing is conducted at connector “E” wherein a check **823** for failed sensor test is made and if present, the pump **412** is turned OFF **825**, the vacuum is released **827** by opening the vent valve, an error message is displayed **829** indicating that the vacuum conduit **430** is blocked, the alarm is turned on **831** and control passes via connector F to wait for intervention by a human operator. The system **400** requires overt operator intervention to restart, such as by answering queries concerning the state of the vacuum conduit **430**.

[0091] If, at decision **796** on FIG. **19***d* there has been no spare switch operation, then the controller checks **826** to see if the Timer is Enabled. If so, a check **828** is made as to whether the timer indicates that the pump(s) should be running. If not, the pump(s) are shut OFF **830**. As before, any occasions of pump control (either turning the pump **412** ON or OFF) present an opportunity to test **833** for pump responsiveness by verifying an appropriate change in vacuum level that has resulted due to the change in pump state. If not, an error is recorded and processing continues at connector "E". In the event **828** that the timer is set to RUN, then the effected pump(s) are either turned ON or left ON, as applicable **832**. Once again a test for change in vacuum level may be conducted, as noted above. Thereafter, the state of the Spare Switch is checked **834** to see if it is ON. If ON, the effected pumps are left running and the processing continues at decision block **820**, otherwise, the effects pump(s) are shut OFF **836**, and a check **837** of vacuum response is conducted.

[0092] FIG. **19***e* depicts error processing. As described above, a failed sensor test **823**, results in turning the pumps OFF **825**, releasing vacuum **827**, posting an error message **829**, and turning the alarm ON **831**. If the error was not due to a failed sensor test, then the controller ascertains **839** if the error was due to an identified loss of pump control, e.g., as indicated by an unexpected vacuum level after turning a pump ON or OFF. If so, the vacuum is released **841** by opening the vent valve, alarms are turned ON **843**, an error message is posted **845**, and a loop of checking **847** for menu key depression is entered. Once a menu key is pressed indicating the intervention of a human operator, Alarms are turned OFF **854**. In the event that the error was not due to a previously identified loss of pump control, verification **838** that all pumps are turned OFF is conducted, e.g., by turning the pumps OFF and ascertaining **849** a drop in vacuum levels, which in the typical case would be to nil. This assumes that the vent valve is positioned or is repositioned to measure vacuum for test **849**. Alternatively, the OFF/ON state of the pumps could be ascertained by measuring the electrical values associated with the pump, e.g., the amount of current passing through the pump motor circuit. Methodology for analyzing pump function based upon electrical measurements is known in the art, e.g., as disclosed in U.S. Pat. No. 4,473,338 to Garmong. A well-known expedient to electrically ascertain whether a motor is running is to measure the electrical current draw of the motor. As before, if the expected vacuum levels indicate lack of motor response, the processing associated with loss of pump control, as determined at step **839**, can be conducted, i.e., steps **841**, **843**, **845**, **847**, etc.

[0093] If the pumps are successfully turned OFF **838** as indicated by the appropriate low vacuum **849**, then the vacuum in the suction conduit **424**, is released **840**, i.e., by repositioning the vacuum solenoid valve **458** to expose the suction conduit **424** to atmosphere or to the pressurized fluid in the accumulator **537**, as applicable. The controller **410** then checks **842** to see if the error is a Hard Stop Error (High Vacuum/vacuum spike, a given number of consecutive errors, a given number of failed attempts to achieve stabilization/prime). If so, the alarm(s), e.g., **427** are turned ON **844**. After three seconds, the vacuum solenoid valve **458** is repositioned **846** to prevent further venting of the suction conduit **424** and/or exposure of the suction conduit **424** to pressurized fluid from the accumulator **537**. The controller then checks **848** to see if the Hard Stop was due to the depression of the Stop Switch **429** (Panic button). If so, the alarm(s) are turned OFF **850**. If the Stop Switch **429** was not pressed, the controller **410** ascertains **852** if the Menu Key has been depressed. If so, the Alarm(s) are turned OFF **854**. If not, the controller **410** pauses for a predetermined time, e.g., ten minutes, during which time the alarm(s), e.g., **427** are sounding. At the end of the pause, the alarm(s) are turned OFF **858**.

[0094] Returning to decision **842**, if the error was not a Hard Stop Error, the controller **410** verifies **860** that the Stop Switch **429** has not been pushed. If it has, the alarm(s), e.g., **427** are turned ON **862** and then there is a predetermined delay period **864**, e.g. three seconds, during which time venting to atmosphere/reverse flow from the accumulator **537** is occurring to reduce the vacuum level at the drains, e.g., **12**, **14** (FIG. **1**). The controller **410** then checks **866** to determine if the Menu Key has been pressed. If so, the vacuum solenoid valve is repositioned **868** to stop venting/reverse flow and the Alarm(s) are turned OFF **870**. In the event that check **866** indicates that the Menu Key was not depressed, then the delay is ended **872** and the vacuum solenoid valve is repositioned **874** to stop venting/reverse flow. Processing continues via connector "6" on FIG. **19***f*, viz., there is a delay **876**, e.g., for seven seconds. During the delay, controller **410** monitors **878** whether the Menu Key is pressed. If so, the Alarm(s) are turned OFF **880** and processing resumes via Connector "A" on FIG. **19***a*. If the Menu Key is not pressed, the entire delay is counted down to the end **882**, at which time, the Alarm(s) are turned OFF. The controller **410** then checks **886** then AC voltage level. If the voltage level is O.K., then processing continues via connector "B" on FIG. **19***c*. Otherwise, processing returns to Connector "6".

[0095] Besides the various queries that are described above, the controller **410** also displays informational messages pertaining to the operational state of the system, error messages, etc., such as: "Calibrating", "Starting Pump", "Stabilizing", "Monitoring", "Stop Switch" (If the Stop Switch is depressed it needs to be reset before the system will resume operation.), "S/Vent Error" (Sensor/Solenoid Venting error—This may occur due to the clogging of the vent **432**), "No Stabilization", "Self Test", "Over Window Vacuum", Under Window Vacuum", "High Vacuum Alert", "System Won't Stabilize", "Too Many Sensor Solenoid Errors or No Prime", "Loss of Motor Control—Relay Stuck Open/Closed", etc.

[0096] In responding to vacuum anomalies characteristic of drain occlusion, the present invention provides for vacuum reduction via venting or reverse pressurized flow in conjunction with pump shut down. The present invention recognizes that it may be preferable in many pool/spa installations for the venting and/or reverse flow to be limited to a relatively short time period, e.g., three seconds. This brief time period is adequate to reduce vacuum at any drain to allow a swimmer to escape drain entrapment. Because the present invention contemplates use of a narrow window of acceptable vacuum levels to provide an enhanced sensitivity to vacuum changes, it is more likely to interpret vacuum levels outside the acceptable window as errors and therefore trigger vacuum reduction and pump shutdown. Due to this enhanced sensitivity, the present invention provides adequate vacuum reduction to allow a swimmer's escape, but without losing the pump's prime and/or interrupting filtration media stability through the introduction of air into the filter system, e.g., **34**. After exceeding a predetermined number of vacuum releases and restarts, the system requires operator intervention, e.g., by interacting with the controller **410**, e.g., by answering questions posed by the controller, which would indicate the pool spa system is safe to use before the controller **410** will allow restarting. Furthermore, the controller **48**, **148**, **410**, **510** of the present invention provides for a selected number of automatic restarts under circumstances which are due to transient non-threatening vacuum variations.

[0097] It should be understood that the embodiments described herein are merely exemplary and that a person skilled in the art may make many variations and modifications without departing from the spirit and scope of the invention. For example, the present invention has been described above in reference to swimming pools and spas, but could be applied to fountains, water features, water park areas, or other installations where water is pumped into a receptacle and is subsequently drained there from. All such variations and modifications are intended to be included within the scope of the present invention.

What is claimed is:

1. A fluid circulation system having a motor-driven pump, comprising:

(A) a sensor for sensing operational parameters of the fluid circulation system indicative of the operational state of the pump;

(B) a computer for receiving the output of said sensor, said computer programmed with a control program and data representing a plurality of criteria values corresponding to a plurality of potential functional states of said pump, said program comparing sensor output to said criteria and selectively generating control outputs to said pump to control the operation of the pump and defining an intended pump state, said program checking output from said sensor to verify that an actual functional state of the pump is consistent with the intended pump state and terminating pump operation when an inconsistency exists.

2. The system of claim **1**, wherein the intended state of said pump is OFF and the output from said sensor has a value indicating a pump ON state, thereby representing an inconsistency.

3. The system of claim **1**, wherein the intended state of said pump is ON and the output from said sensor has a value indicating a pump OFF state, thereby representing an inconsistency.

4. The system of claim **1**, wherein said pump is a multi-speed pump, the intended state of said pump is low speed and the output from said sensor has a value indicating high speed.

5. The system of claim **1**, wherein said control program checks the output of said sensor after generating control output to said pump to change the functional state of said pump.

6. The system of claim **1**, wherein said control program checks the output of said sensor before generating control output to said pump to change the functional state of said pump.

7. The system of claim **1**, wherein said circulation system has a fluid receptacle with a fluid outlet through which fluid exits the receptacle, a fluid inlet for returning fluid to the receptacle, said pump moving the fluid from the fluid outlet to the fluid inlet, a suction conduit providing fluid communication between the fluid outlet and said pump and a return conduit providing fluid communication between the pump and the fluid inlet, further including a vent valve having at least two positions, a first position which fluidly connects the suction conduit to matter outside the suction conduit and a second position which isolates the suction conduit from matter outside the suction conduit; said program comparing sensor output to said criteria and selectively generating control output to said vent valve to control the position of the vent valve, such that when the actual functional state of the pump is inconsistent with the intended pump state, said vent valve is placed in the first position.

8. The system of claim **7**, wherein said sensor is a vacuum sensor which communicates with said suction conduit when said vent valve is in the second position.

9. The system of claim **1**, further including a plurality of pumps, and wherein said sensor senses operational parameters of the fluid circulation system indicative of the operational state of said plurality of pumps.

10. A controller system for a fluid containment and circulation system having a fluid receptacle with a fluid outlet through which fluid exits the receptacle, a fluid inlet for returning fluid to the receptacle, a pump that moves the fluid from the fluid outlet to the fluid inlet, a suction conduit providing fluid communication between the fluid outlet and the pump and a return conduit providing fluid communication between the pump and the fluid inlet, comprising:

(A) a sensor for sensing operational parameters of the fluid containment and circulation system indicative of the operational state thereof and producing corresponding output;

(B) a vent valve having at least two positions, a first position which fluidly connects the suction conduit to matter outside the suction conduit and a second position which isolates the suction conduit from matter outside the suction conduit;

(C) a computer for receiving the output of said sensor, said computer programmed with a program that compares the sensor output to at least one predetermined criteria and selectively generates first control output to said vent valve to control the position of said vent valve and to the pump to control the operation of the pump, based upon said sensor output, said computer testing output from said sensor after generating said first control output to verify that said first control output has resulted in achieving an intended functional state of said fluid containment and circulation system and said controller system associated with said first control output.

11. The system of claim **10**, wherein the sensed operational parameter is a level of vacuum present in the suction conduit and said sensor is a vacuum sensor.

12. The system of claim **10**, wherein the computer generates second control output to turn said pump OFF and open said vent valve when the intended functional state associated with said first control output is not verified.

13. The system of claim **12**, further including a perceptible alarm and wherein said second control output include an output to turn said alarm ON when the intended functional state is not verified.

14. The system of claim **12**, wherein the intended functional state is a reduction in pump output relative to a prior functional state and an expected associated sensed parameter is a reduced vacuum level relative to that which persisted prior to the control output intended to reduce pump output.

15. The system of claim **14**, wherein the reduction in pump output is to nil resulting in an expected corresponding vacuum level of approximately nil.

16. A method for controlling a fluid pump in a fluid circulation system having a sensor for sensing operational parameters of the fluid circulation system indicative of the operational state of the pump, a computer for receiving the output of said sensor, the computer programmed with a control program and data representing a plurality of criteria values corresponding to a plurality of potential functional states of the pump, comprising the steps of:

(A) the control program selectively generating control output to the pump to control the operation of the pump, thereby defining an intended pump state;

(B) the control program comparing output from the sensor to a criteria value to verify that the actual functional state of the pump is consistent with the intended pump state; and

(C) terminating pump operation when an inconsistency exists.

17. The method of claim **16**, wherein said step (B) is conducted after a control output is generated to change the pump from an ON state to an OFF state, to verify that the previously running pump has actually been turned OFF.

18. The method of claim **16**, wherein said step (B) is conducted before a control output is generated to change the pump from an OFF state to an ON state, to verify that the pump which was expected to be OFF based upon the program and the data pertaining to the state of the pump is actually OFF.

19. The method of claim **16**, wherein the sensor is a vacuum sensor and the criteria pertains to vacuum level.

20. The method of claim **16**, wherein the circulation system has a fluid receptacle with a fluid outlet through which fluid exits the receptacle, a fluid inlet for returning fluid to the receptacle, the pump moving the fluid from the fluid outlet to the fluid inlet, a suction conduit providing fluid communication between the fluid outlet and the pump and a return conduit providing fluid communication between the pump and the fluid inlet, a vent valve having at least two positions, a first position which fluidly connects the suction conduit to matter outside the suction conduit and a second position which isolates the suction conduit from matter outside the suction conduit, further comprising the step of generating a control output to said vent valve to place the vent valve into the first position when the actual functional state of the pump is inconsistent with the intended pump state.

21. The method of claim **16**, wherein the intended pump state is a state of being primed and further comprising the steps of measuring a first time required for achieving the state of being primed; recording the first time; using the recorded first time in a priming time criteria; subsequently running the system to achieve the state of prime and measuring a subsequent time to achieve the state of being primed; comparing the subsequent time to the priming time criteria; and invoking error processing if the subsequent time does not meet the priming time criteria.

22. The method of claim **21**, wherein the step of using includes expanding the first time with a tolerance range to define the priming time criteria.

23. The method of claim **22**, further including the step of adjusting the priming time criteria to adapt to changes in resistance to fluid flow.

24. The method of claim **16**, wherein the intended pump state is a state of being primed and said sensor is a vacuum sensor disposed in communication with a suction side of the pump and wherein said step of comparing includes comparing a present vacuum level indicated by the vacuum sensor to a prior vacuum level while the pump is priming to ascertain when the vacuum level stops increasing and recording the time as an endpoint in a time period defining a time for priming.

25. The method of claim **24**, further comprising the step of utilizing a vacuum value present at the endpoint in the time for priming in calculating a vacuum criteria value.

26. The method of claim **25**, further comprising the steps of calculating a priming time criteria by adding a range period to the period defining a time for priming and adding a vacuum range value to the vacuum value present at the endpoint in said step of calculating the vacuum criteria.

27. A fluid circulation system having a motor-driven pump, comprising:

(A) a sensor for sensing operational parameters of the fluid circulation system indicative of the operational state of the pump, including the pressure level present on the suction side of the pump;

(B) a computer for receiving the output of said sensor, said computer programmed with a control program and data representing a criteria value, said data at least partly derived from empirical data output from the sensor obtained from a first running of the system, said program comparing subsequent sensor output to said criteria value and selectively generating control outputs to said pump to control the operation of the pump, said criteria value being adjustable based upon the subsequent sensor output to adapt to changes in fluid flow resistance in the system.

28. The system of claim **27**, wherein the criteria is automatically adjusted so long as the resultant adjusted criteria value falls within a previously defined acceptable range.

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