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Dickhart et al.

[11] **3,793,825**

[45] **Feb. 26, 1974**

[54] TIME DELAY GAS TURBINE STARTING SYSTEM WITH FUEL PRESSURE AND FLAME SENSING CIRCUITRY

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[73] Assignee: **Ford Motor Company**, Dearborn, Mich.

[22] Filed: **Jan. 27, 1972**

[21] Appl. No.: **221,325**

[52] **U.S. Cl.** .... **60/39.14 R,** 60/223

[51] **Int. Cl.** **F02c 7/26**

[58] **Field of Search** 60/39.14, 223

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Primary Examiner—Carlton R. Croyle
Assistant Examiner—Warren Olsen
Attorney, Agent, or Firm—Donald J. Harrington; Keith L. Zerschling

[57] **ABSTRACT**

A fuel pressure sensing switch prevents actuation of a starter motor until after fuel pressure at the nozzle reaches a predetermined level. This arrangement prevents air flow from reaching a velocity at which ignition is difficult before adequate fuel is present. The electrical system also includes a control battery and a supplemental battery that are connected in parallel for normal system operation and recharging and are connected in series across the starter motor during starter motor operation.

8 Claims, 8 Drawing Figures

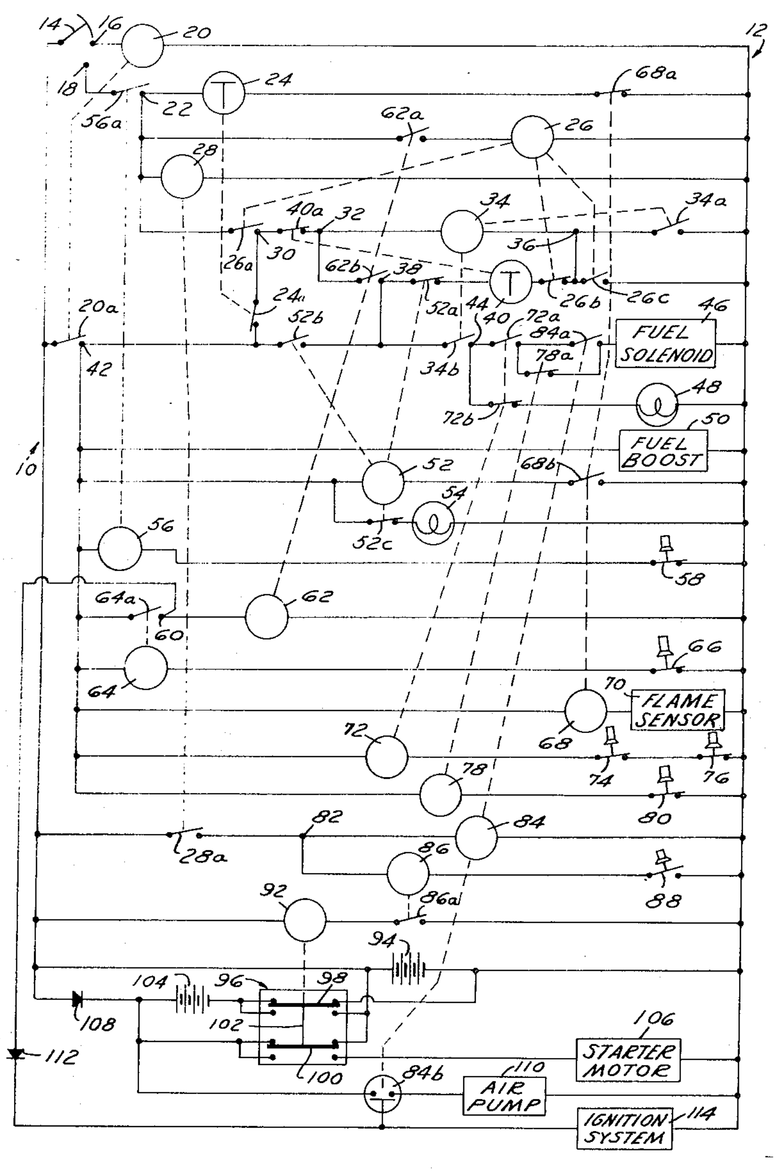


FIG. 1

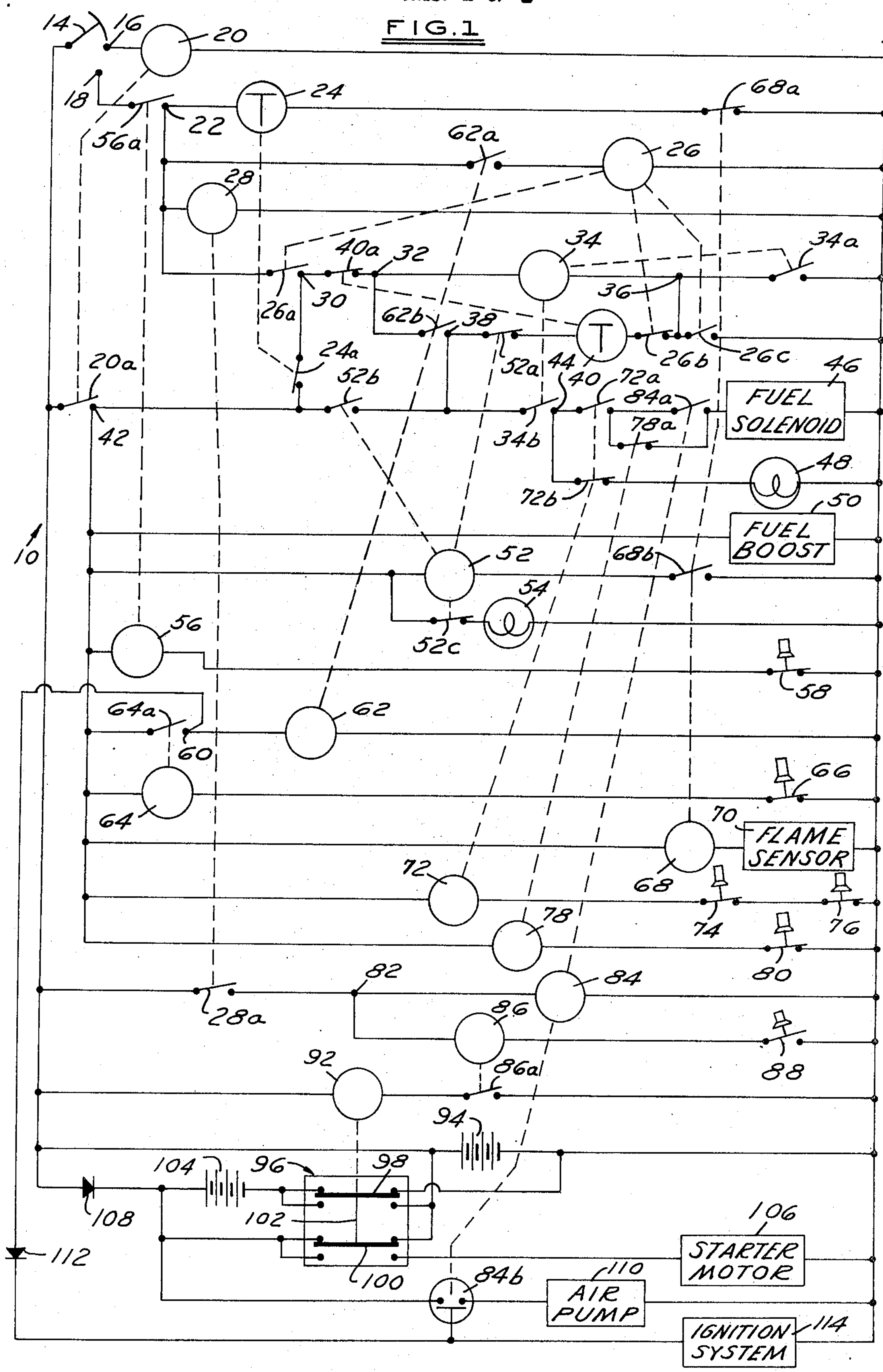

FUEL SOLENOID
FUEL BOOST
FLAME SENSOR
STARTER MOTOR
AIR PUMP
IGNITION SYSTEM

FIG. 2

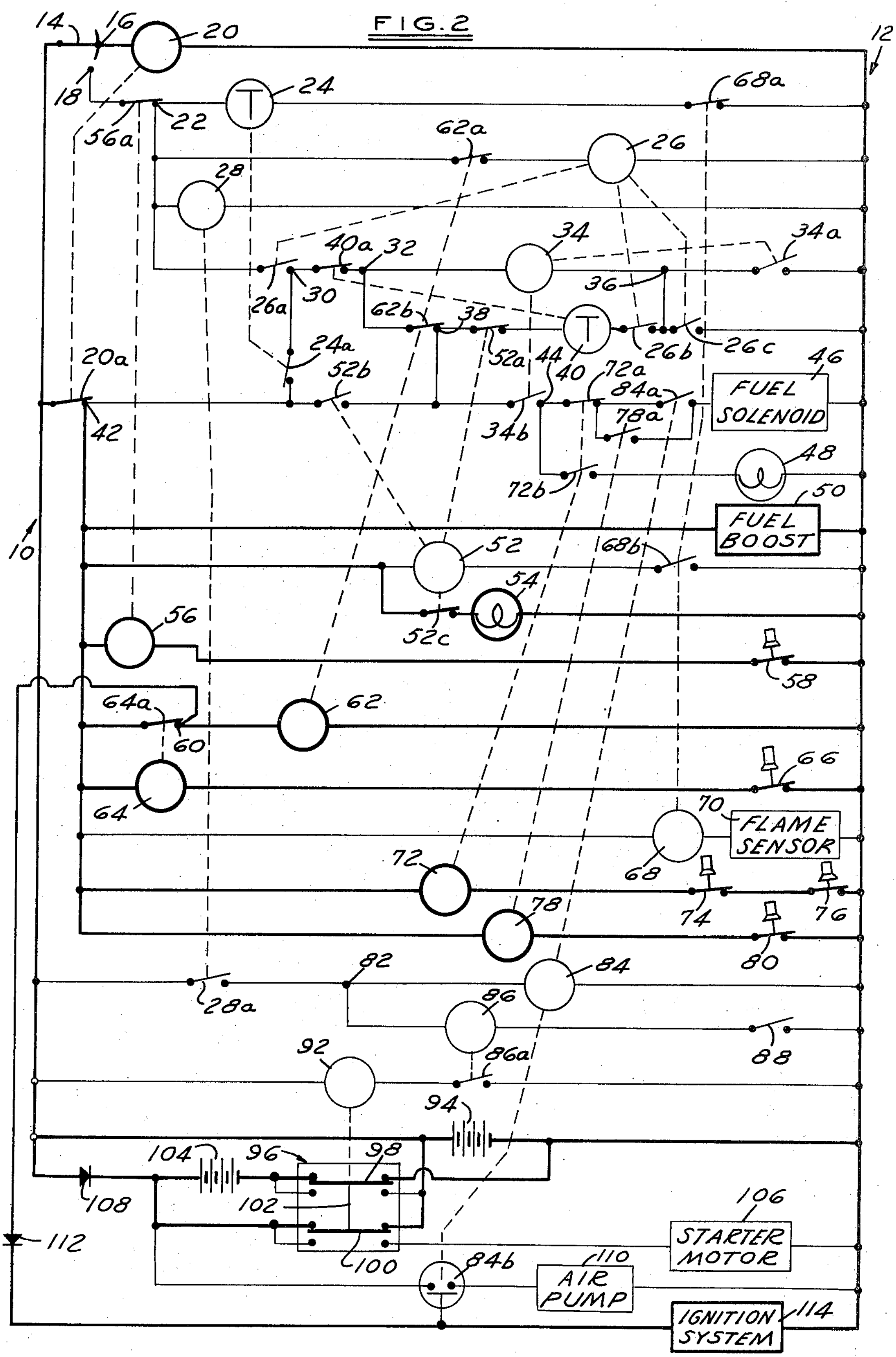
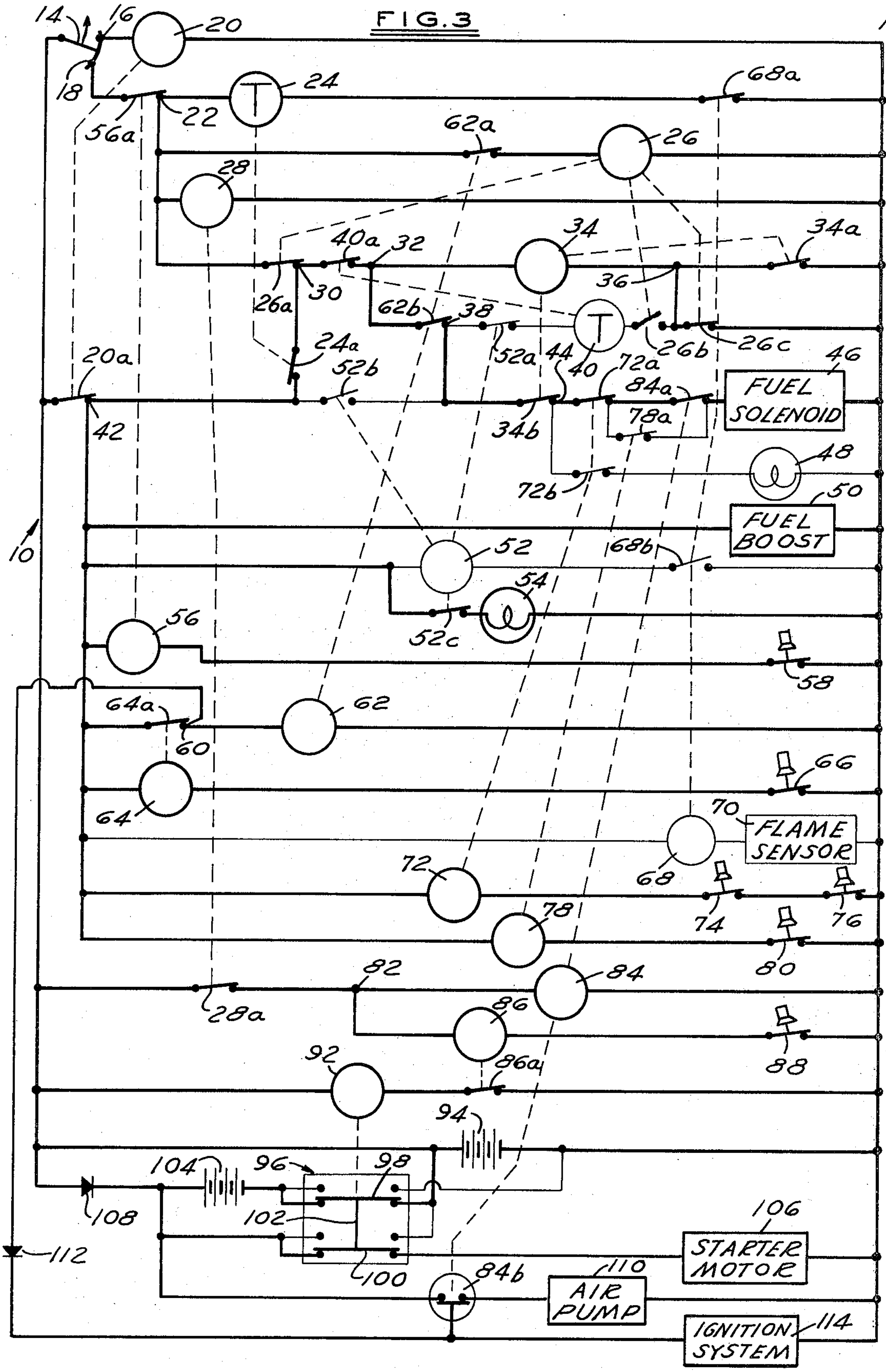

FUEL SOLENOID
FUEL BOOST
FLAME SENSOR
STARTER MOTOR
AIR PUMP
IGNITION SYSTEM

FIG. 3


14
16
20
12
18
24
68a
56a
22
62a
26
28
40a
32
34
34a
36
26a
30
62b
38
26b
26c
24a
52b
52a
44
40
72a
46
20a
84a
FUEL SOLENOID
42
34b
78a
48
72b
50
FUEL BOOST
10
52
68b
54
56
52c
58
64a
62
60
66
64
70
FLAME SENSOR
68
72
74
76
78
80
82
84
28a
86
88
92
86a
94
104
96
98
108
102
106
STARTER MOTOR
112
100
84b
110
AIR PUMP
IGNITION SYSTEM
114

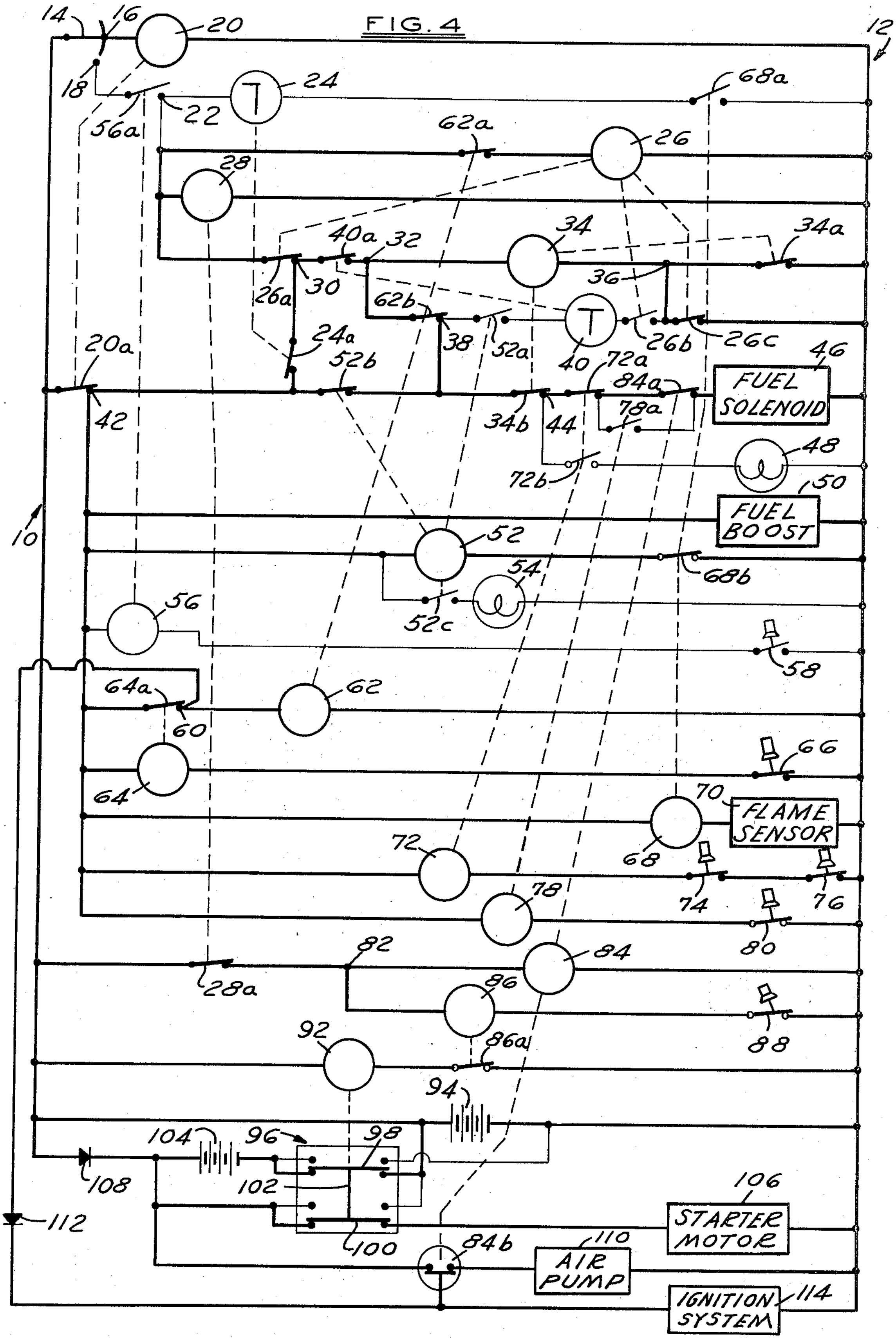


FIG. 4
FUEL SOLENOID
FUEL BOOST
FLAME SENSOR
STARTER MOTOR
AIR PUMP
IGNITION SYSTEM

FIG. 5

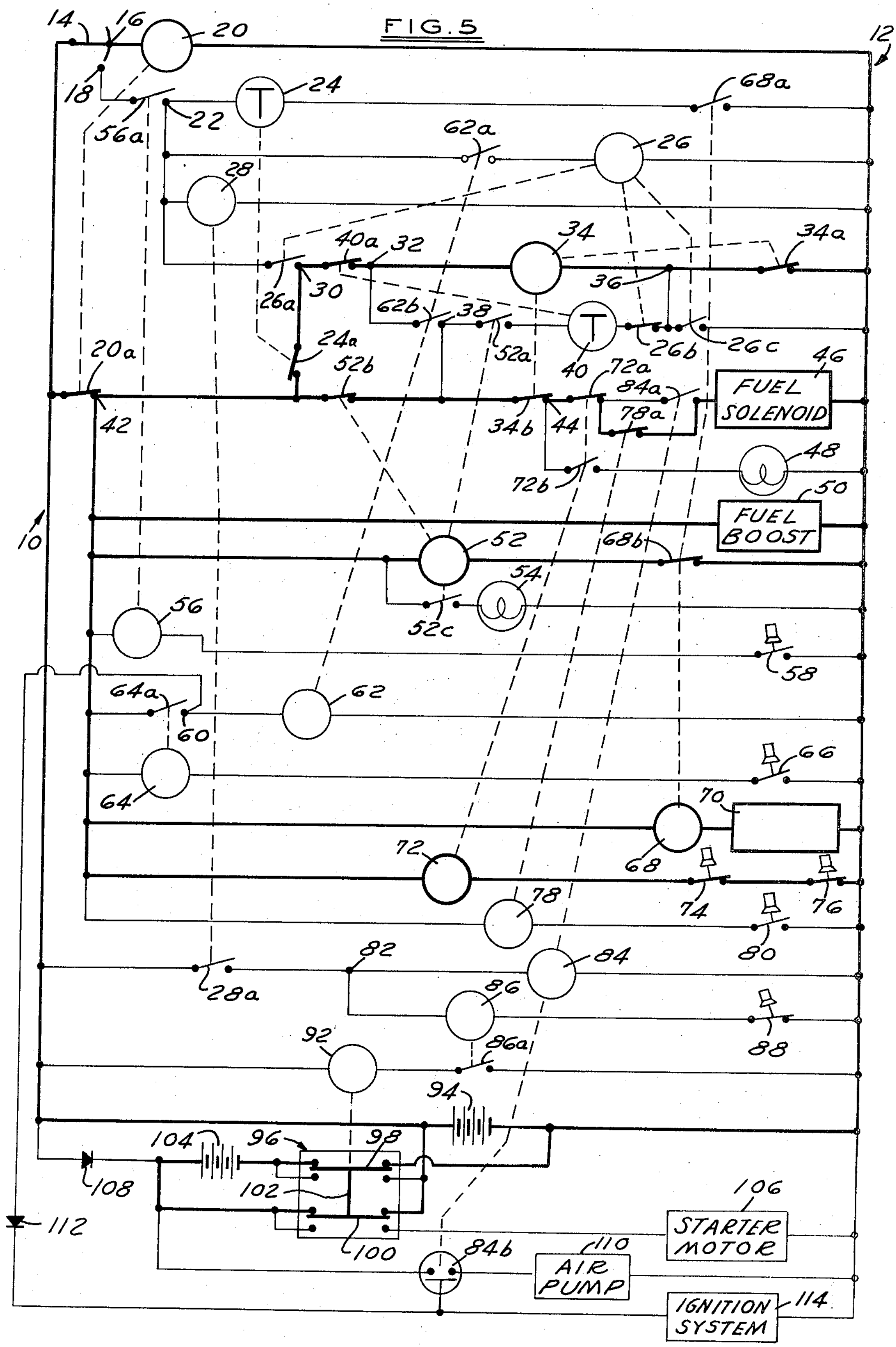
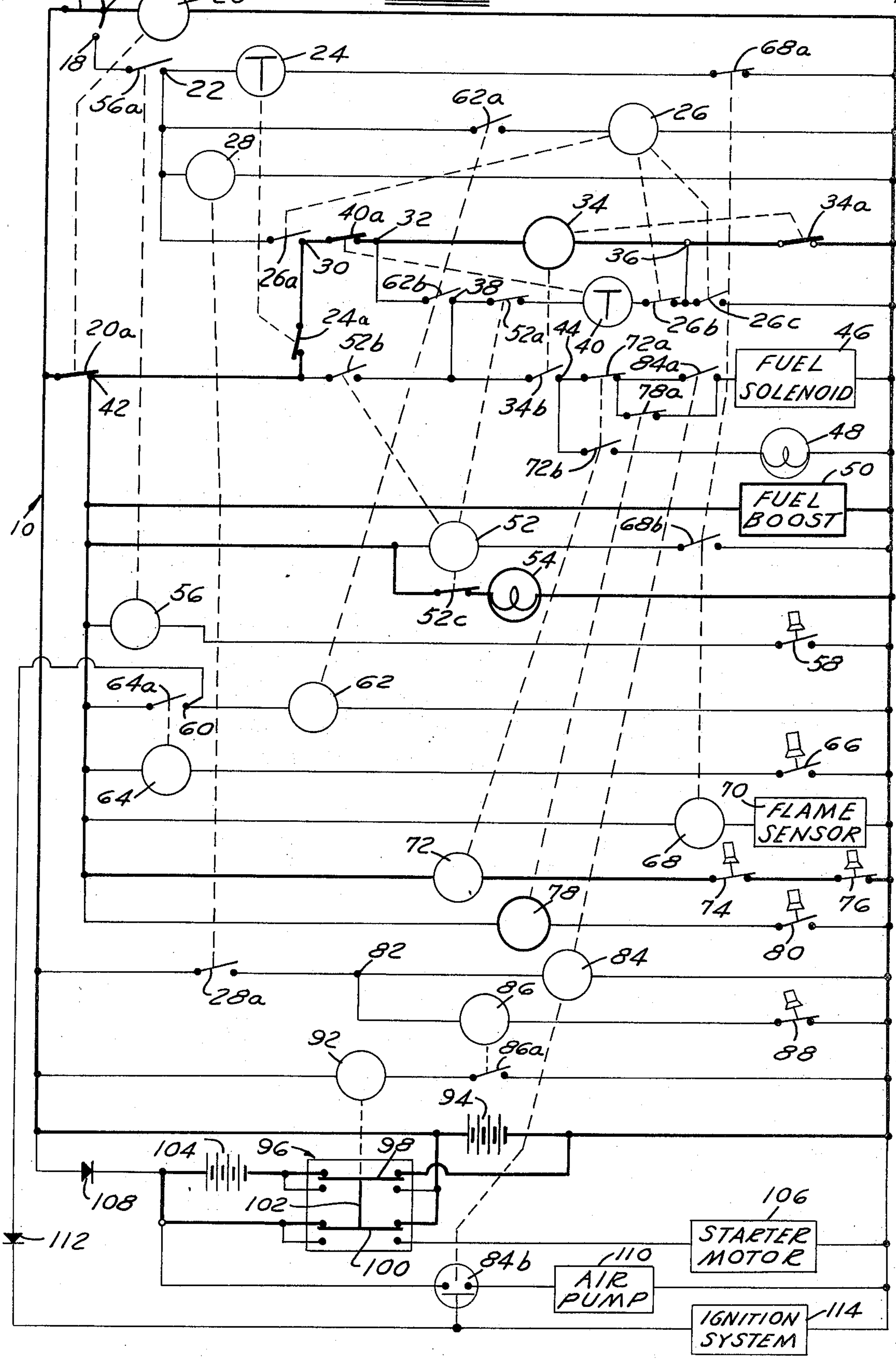

FUEL SOLENOID
FUEL BOOST
STARTER MOTOR
AIR PUMP
IGNITION SYSTEM

FIG. 6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40a
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26a
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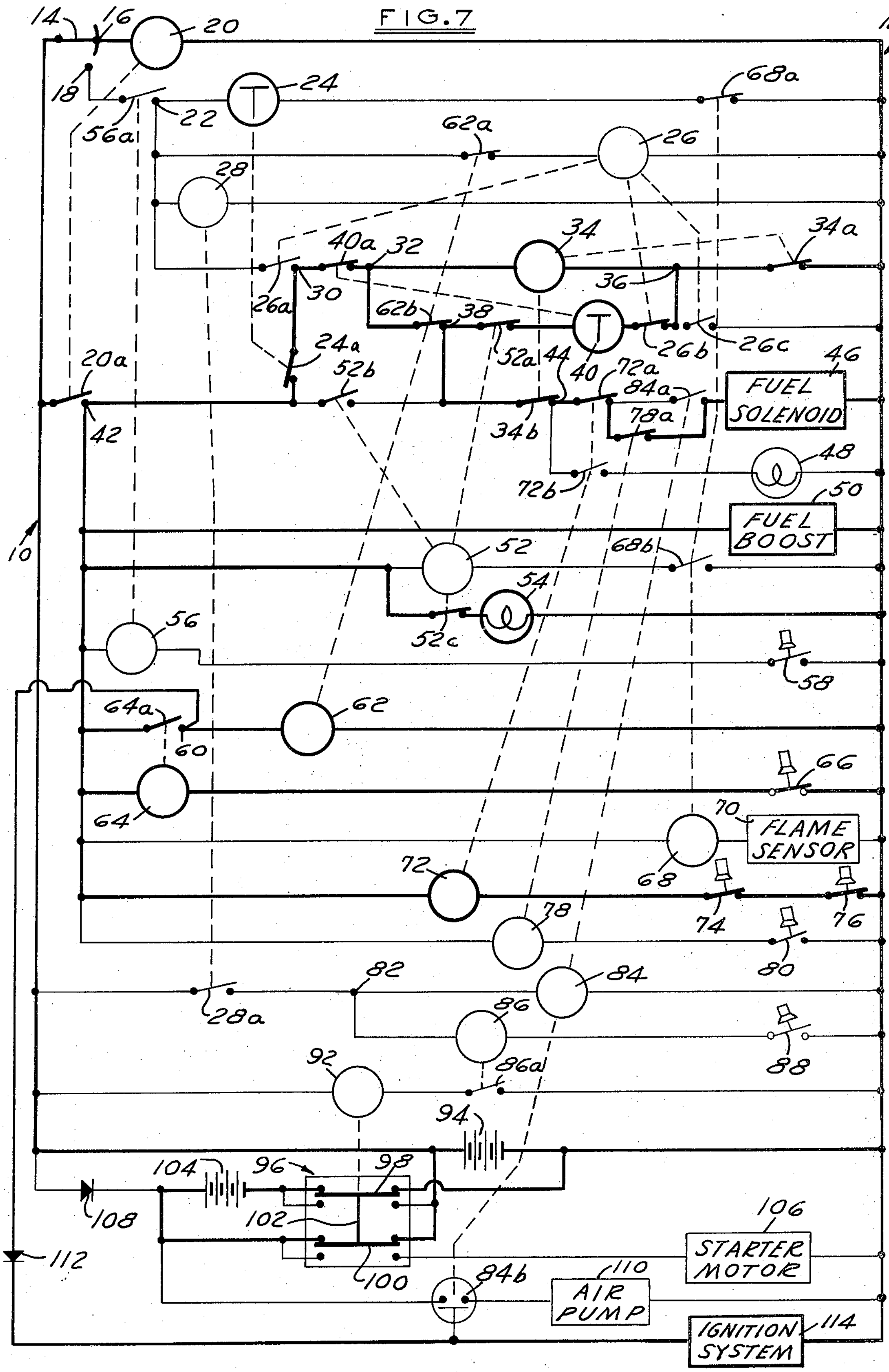
36
62b
38
24a
52b
52a
44
40
26b
26c
20a
72a
84a
46
FUEL SOLENOID
42
78a
34b
48
72b
50
FUEL BOOST
10
52
68b
54
52c
56
58
64a
60
62
66
64
70
FLAME SENSOR
68
72
74
76
78
80
82
84
28a
86
88
92
86a
94
104
96
98
108
102
106
STARTER MOTOR
112
100
84b
110
AIR PUMP
IGNITION SYSTEM
114

FIG.7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18
24
68a
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56a
62a
26
28
34
34a
40a
32
36
26a
30
62b
38
26b
26c
24a
52b
52a
44
40
72a
84a
46
20a
FUEL SOLENOID
42
34b
78a
72b
48
50
FUEL BOOST
10
52
68b
54
56
52c
58
64a
62
60
66
64
70
FLAME SENSOR
68
72
74
76
78
80
82
84
28a
86
88
92
86a
94
104
96
98
108
102
106
STARTER MOTOR
112
100
110
84b
AIR PUMP
IGNITION SYSTEM
114

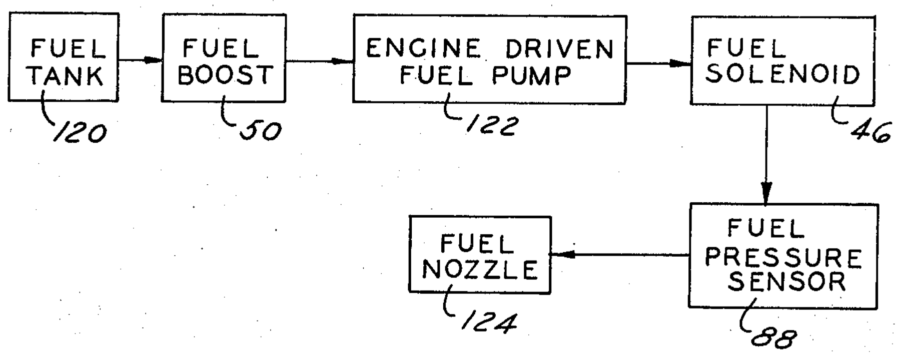
FUEL TANK
120
FUEL BOOST
50
ENGINE DRIVEN FUEL PUMP
122
FUEL SOLENOID
46
FUEL PRESSURE SENSOR
88
FUEL NOZZLE
124

FIG. 8

TIME DELAY GAS TURBINE STARTING SYSTEM WITH FUEL PRESSURE AND FLAME SENSING CIRCUITRY

SUMMARY OF THE INVENTION

This invention relates to and is assigned to the assignee of U. S. Pat. No. 3,600,887 to Gault et al.

Prior art starting systems for gas turbine engines actuate a starter motor immediately upon initiation of the starting cycle. In most cases this conventional approach functions satisfactorily, but under certain conditions such as cold weather starting, high fuel viscosity can delay fuel flow to the combustion chamber until after air flow produced by engine rotation exceeds the relatively low levels conducive to ignition. Additionally, most prior art starting systems rely upon a single battery to power the appropriate relays in the starting and operating circuit and power the starter motor.

In the starting system of this invention, a fuel pressure sensing device prevents starter actuation until after fuel pump operation produces a predetermined fuel pressure at the fuel nozzle. The system also reduces battery size and increases overall electrical efficiency by using two batteries that are connected in parallel to provide power to the circuit components but are connected in series across the starter motor for starter motor actuation. In a gas turbine engine having a starter motor and a fuel supply system that includes an electrical fuel pump for supplying pressurized fuel to the engine, the starting control system comprises an electrical energy source, a manually actuated switch for connecting the energy source to the fuel pump to initiate operation of the fuel pump, a fuel pressure sensing device for sensing when the fuel pressure reaches a predetermined value, and a switch connected to the fuel pressure sensing device for actuating the starter motor only after fuel pressure reaches the predetermined value. A switch mechanism normally connects two batteries making up the electrical energy source in parallel with each other for supplying power to the relays and other components of the system and to a charging mechanism. During starter motor actuation, the switch mechanism connects the two batteries in series across the starter motor and thereby greatly reduces the current required by the starter motor. During starting, the switch mechanism also can connect the two batteries in series across the ignition system and a supplemental air pump that urges a fuel air mixture toward an ignitor of the ignition system.

If a flame is not sensed within a predetermined time limit, usually about 4 seconds, after initiation of the starting cycle, the starting cycle is aborted and the engine is allowed to coast to a halt before another starting cycle is attempted. If a flame is sensed within the predetermined time limit, the starter motor, ignition system, and supplemental air pump remain actuated until gas generator speed reaches a self sustaining level. A flameout during this period does not abort the starting cycle unless a flame is not reestablished within the predetermined time limit. A starter lockout relay prevents manual reactuation of the starter motor whenever engine speed exceeds a predetermined value, typically about 10 percent of design speed.

The fuel supply system preferably includes an engine driven fuel pump in series with the electrical fuel pump and a fuel nozzle located in the engine combustion chamber. A fuel pressure boosting function then is provided by the electrical fuel pump, which is particularly useful during engine starting. The ignition system preferably is actuated by both a series connection and a parallel connection of the batteries. During starter motor actuation, the ignition system is connected to a series connection of the batteries to insure strong ignition system operation despite the large voltage drop caused by the current drain of the starter motor under low temperature starting conditions.

BRIEF DESCRIPTION OF THE DRAWINGS

In FIGS. 1 – 7 of the drawings, the windings of relays are represented by circles. Switches actuated by each relay are connected to the relay by dashed lines and are designated by the relay number with a letter suffix.

FIG. **1** is a schematic circuit diagram of a control system of this invention showing the relays and switches in unactuated conditions. In FIGS. **2 - 7,** actuates switches, relays, lights and connecting leads are designated by heavy lines.

FIG. **2** shows the condition of the circuit after the manual switch has been moved to the on position in preparation for a starting cycle.

FIG. **3** shows the circuit condition after the manual switch has been moved momentarily to the start position. The manual switch is spring loaded to return to the on position as indicated by the arrow associated therewith in FIG. **3.**

FIG. **4** shows the circuit configuration after a flame has been sensed in the engine combustion chamber and engine speed has exceeded the point at which reactuation of the starter motor would be detrimental to starter and engine components.

FIG. **5** shows the circuit after engine speed has reached a self sustaining value and operation of the starter motor, air pump and ignition system has been discontinued. The circuit arrangement of FIG. **5** remains in effect during normal engine operation.

FIG. **6** shows the circuit when a flameout is sensed at an engine speed exceeding the self sustaining value. The control circuit does not attempt an immediate relighting but waits until engine speed declines approximately to idling speed at which time the circuit makes one relighting attempt by switching to the configuration shown in FIG. **7.**

FIG. **8** is a schematic of a fuel flow system useful with the electrical circuitry of FIGS. **1 – 7.**

DETAILED DESCRIPTION

Referring to FIG. **1** of the drawings, the control system of this invention comprises a main bus lead **10** and a ground lead **12.** A manually actuable switch **14** similar to the conventional automotive ignition switch is connected to main lead **10** and is movable to an operating position where it connects main lead **10** to an operating contact **16** and to a starting position where it connects main lead **10** to both operating contact **16** and a starting contact **18.** The switch pole is spring loaded so that releasing the switch while in the starting position returns the pole to the operating contact. A relay **20** connects operating contact **16** to ground lead **12.**

A normally open switch **56*a*** connects starting contact **18** with a junction **22.** A time delay relay **24** in series with a normally closed switch **68*a*** connects junction **22** to ground lead **12.** A normally open switch **62*a*** in series with a relay **26** connects junction **22** to ground lead 12. A relay 28 connects junction 22 to ground lead 12. A normally open switch 26*a* connections junction 22 to a junction 30. Junction 30 is connected by a normally closed switch 40*a* to a junction 32 and a relay 34 connects junction 32 to a junction 36. A normally open switch 34*a* connects junction to ground lead 12.

Junction 32 is connected by a normally open switch 62*b* to a junction 38. A normally closed switch 52*a* in series with a time delay relay 40 and a normally closed switch 26*b* connects junction 38 to junction 36. Junction 36 is connected by a normally open switch 26*c* to ground lead 12.

A normally open switch 20*a* connects main lead 10 to a junction 42 that is connected by a normally closed switch 24*a* to junction 30 and by a normally open switch 52*b* to junction 38. A normally open switch 34*b* connects junction 38 to a junction 44. Junction 44 is connected by a normally open switch 72*a* in series with a normally open switch 84*a* and a fuel solenoid 46 to ground lead 12. Switch 84*a* is in parallel with a normally closed switch 78*a*. Junction 44 also is connected to ground lead 12 by a normally closed switch 72*b* in series with a combined overspeed-overtemperature warning light 48.

Fuel boost pump 50 connects junction 42 with ground lead 12. Junction 42 also is connected to ground lead 12 by a relay 52 in series with a normally open switch 68*b* and by a normally closed switch 52*c* in series with a flameout light 54. A starter lockout relay 56 in series with a speed sensing switch 58 connects junction 42 to ground lead 12. Speed sensing switch 58 typically opens when engine rotational speed rises above about 12 percent of design speed and closes when engine rotational speed falls below about 10 percent of design speed. A normally open switch 64*a* connects junction 42 to a junction 60. Junction 60 is connected by a relay 62 to ground lead 12. A relay 64 in series with a speed sensing switch 66 connects junction 42 to ground lead 12. Speed sensing switch 66 typically is open at engine speeds exceeding about 42 percent of design speed.

Relay 68 in series with a flame sensing device 70 connects junction 42 to ground lead 12. Flame sensing device 70 can be an ultraviolet light sensor assembly that changes from a high impedance to a low impedance when a flame appears in the engine combustion chamber. A relay 72 in series with an overtemperature sensing switch 74 and an overspeed sensing switch 76 connect junction 42 to ground lead 12. Temperature sensing switch 74 is closed normally but opens when engine temperature exceeds a predetermined maximum. Speed sensing switch 76 is closed normally but opens when engine speed exceeds a predetermined maximum. A relay 78 in series with an oil pressure sensing switch 80 connect junction 42 to ground lead 12. Oil pressure switch 80 is closed normally but opens when engine oil pressure exceeds some predetermined minimum.

A normally open switch 28*a* connects main lead 10 to a junction 82. A relay 84 connects junction 82 to ground lead 12. Junction 82 also is connected to ground lead 12 by a relay 86 in series with a normally open fuel pressure sensing switch 88. Fuel pressure sensing switch 88 closes when fuel pressure at the injection nozzle exceeds a predetermined value, typically about 2–4 psi. A starter relay 92 in series with a normally open switch 86*a* connect main lead 10 to ground lead 12.

An electrical storage battery 94 has its positive terminal connected to main lead 10 and its negative terminal connected to ground lead 12. Relay 92 operates a starter switch 96 that comprises two switch poles 98 and 100 connected to each other by an insulating bar 102. Pole 98 normally connects the negative terminal of battery 94 to the negative terminal of a second battery 104. Both batteries 94 and 104 typically are 12 volts. Pole 100 normally connects the positive terminal of battery 94 to the positive terminal of battery 104. When switch 96 is actuated, pole 98 connects the positive terminal of battery 94 to the negative terminal of battery 104 and pole 100 connects the positive terminal of battery 104 through a starter motor 106 to ground lead 12. The cathode of a diode 108 is connected to the positive terminal of battery 104 and its anode is connected to main lead 10.

The positive terminal of battery 104 is connected to one terminal of a switch 84*b*. Another terminal in switch 84*b* is connected through an air pump 110 to ground lead 12. Air pump 110 provides supplemental air flow within the engine combustion chamber that urges air and fuel toward the ignitor of the ignition system. A diode 112 connects terminal 60 to the pole of switch 84 and through the ignition system 114 to ground lead 12. Actuation of switch 84*b* moves its pole into contact with both of the terminals in the switch.

Turning for a moment to FIG. 8, the inlet of fuel pump 50 is connected to a fuel tank 120 and its outlet is connected to an engine driven fuel pump 122. The outlet of pump 122 is connected to fuel solenoid 46. Fuel pressure sensor 88 is connected between the outlet of solenoid 46 and a fuel nozzle 124 located in the engine combustion chamber. Fuel pressure produced by operation of fuel boost pump 50 is transmitted through the engine driven fuel pump even though the latter is not operating. Fuel nozzle 124 imposes a sufficient flow restriction on the fuel to produce a pressure signal at sensor 88.

OPERATION

Operation of the system is illustrated in FIGS. 2 – 7 of the drawings. A starting cycle begins by moving manual switch 14 to contact 16 as shown in FIG. 2. Energized relay 20 closes switch 20a and thereby applies the potential of the parallel connection of batteries 94 and 104 to junction 42. Fuel pump 50 and flameout light 54 are energized and energized relay 56 closes switch 56*a*. Energized relay 64 closes switch 64*a* and thereby energizes relay 62 which closes switch 62*a* and 62*b*. Energized relay 72 closes switch 72*a* and opens switch 72*b*. Relay 78 opens switch 78*a*.

Switch 64*a* also connects the voltage in bus lead 10 across ignition system 114. The ignition system is energized by a minimum of about 8 volts so such connection energizes the ignition system.

The starting cycle continues with manual movement of switch 14 into contact with terminal 18 as well as terminal 16 as shown in FIG. 3. Contact with terminal 18 needs to be only momentary and the spring mechanism associated with switch 14 returns the pole of switch 14 to terminal 16 after the switch is released by the vehicle operator. The momentary contact energizes relay 26 which closes switch 26*a* and thereby connects junction 42 through switches 24*a* and 26*a* to junction 22. Energized relay **26** also opens switch **26***b* and closes switch **26***c*. The time delay period of relay **24** begins running. Relay **28** is energized to close switch **28***a* and relay **34** is energized to close switches **34***a* and **34***b*. Switches **62***b*, **34***b*, **72***a* and **84***a* apply electrical potential across fuel solenoid **46** and thereby open the solenoid.

When fuel pressure at the fuel nozzle reaches the preset actuation point of fuel pressure sensing switch **88**, switch **88** closes and thereby energizes relay **86** which closes switch **86***a*. Energized relay **92** moves poles **98** and **100** of switch **96** to a lower position where pole **98** connects the positive terminal of battery **94** to the negative terminal of battery **104** and pole **100** connects the positive terminal of battery **104** through starter motor **106** to ground lead **12**. The starter motor thus is connected across batteries **94** and **104** in series. Switch **84**b connects the positive terminal of battery **104** through air pump **110** to ground lead **12** and also connects the positive terminal of battery **104** through ignition system **114** to ground lead **12**. At this point, the starter motor is cranking the engine which is receiving supplemental air from air pump **110**, ignition energy from ignition system **114**, and pressurized fuel having at least a predetermined pressure level from fuel pump **50** via open fuel solenoid **46**.

Assuming that the starting cycle proceeds properly, the next event is the occurrence of a flame within the combustion chamber. Flame sensor **70** energizes relay **68** which opens switch **68***a* and closes switch **68***b* (see FIG. 4). Switch **68***a* deenergizes time delay relay **24**. Switch **68***b* energizes relay **52** which opens switch **52***a*, closes switch **52***b* and opens switch **52***c*. Switch **52***b* connects junction **42** directly to fuel solenoid **46**. Switch **52***c* extinguishes the flameout light **54** and thereby indicates to the vehicle operator that a flame exists within the combustion chamber. As engine rotational speed increases through the predetermined setting of speed sensing switch **58**, switch **58** opens and thereby deenergizes relay **56** which opens switch **56***a*. Opening switch **56***a* serves a starter lockout function by preventing subsequent manual reactuation of the starter motor until engine speed has declined below the setting of switch **58**.

Turning now to FIG. **5**, continued acceleration of the engine produces sufficient oil pressure to open switch **80** and eventually reaches the preset point of speed sensing switch **66**. Switch **80** deenergizes relay **78** to close switch **78***a*. Switch **66** opens to deenergize relay **64** which in turn opens switch **64***a* to deenergize relay **62**. Switch **62***a* opens to deenergize relay **26** which opens switch **26***a* and thereby deenergizes relay **28**. Relay **28** opens switch **28***a* to deenergize both relays **84** and **86**.

Relay **84** opens switch **84***a* and **84***b*. Note that if oil pressure sensing switch **80** has not opened previously to deenergize relay **78** and thereby close switch **78***a*, fuel solenoid **46** will close and thereby halt engine operation. Relay **86** deenergizes relay **92** which returns starter switch **96** to its original position where it disconnects starter motor **106**, air pump **110**, and ignition system **114** from the series connection of batteries **94** and **104**. The circuit retains the FIG. **5** configuration for all subsequent normal operation.

FIG. 6 shows the circuit configuration immediately after a flameout has occurred at an engine speed exceeding the normal idling speed. Flame sensor **70** has deenergized relay **68**, thereby closing switch **68***a* and opening switch **68***b*. Switch **68***b* deenergizes relay **52** which closes switch **52***a* and **52**c and opens switch **52***b*. Switch **52***c* illuminates light **54** to indicate to the vehicle operator that a flameout has occurred. Switch **52***b* disconnects the fuel solenoid **46** and thereby cuts off fuel flow to the engine.

The system of the invention provides for one relighting attempt at a speed approximating the idling speed. FIG. 7 shows the circuit configuration when engine speed has declined to the desired value, which is the speed at which speed sensing switch **66** closes. Relay **64** closes switch **64***a* and thereby energizes relay **62** which closes switches **62***a* and **62***b*. Switch **62***b* connects junction **42** through switches **34***b*, **72***a* and **78***a* to fuel solenoid **42.** Solenoid **42** opens and reestablishes the supply of fuel to the combustion chamber. Switch **64**a also activates the ignition system **114.** Switch **52***a* begins the time delay of relay **40.**

If reignition occurs before the time delay period of relay **40** expires, relay **68** energizes relay **52** to stop the time delay period and reestablish the position shown in FIG. **5** of switches **52***a*, **52***b* and **52***c*. When engine speed exceeds the preset speed of switch **66**, relay **64** is deenergized.

Turning back to FIG. **3**, if during cranking a flame does not appear before the time delay of relay **24** expires, relay **24** is energized to open switch **24***a*. Since the pole of switch **14** no longer touches contact **18**, opening switch **24***a* deenergizes relays **26**, **28** and **34** and also deenergizes fuel solenoid **46.** Deenergized relay **28** opens switch **28***a* which deenergizes relays **84** and **86.** Relay **86** in turn deenergizes starter relay **92** and thereby terminates the starting cycle. Another starting cycle can be initiated after relay **24** resets.

Flame sensing assemblies other than the ultraviolet type can be used as flame sensor **70.** It is interesting to note that the system of the invention energizes the ignition system under a variety of circumstances. Note, for example, that the ignition system remains energized even after the delays of either time delay relay expire to ignite if possible whatever excess fuel remains in the combustion chamber and remains energized during cranking under cold weather conditions where the voltage of each battery can decline as low as 4 volts.

A light can be included in series with relay **92** to indicate to the engine operator that the starter motor is being energized. Reverse biased diodes can be connected in parallel with one or more relays to prevent physical shock and vibration from momentarily deenergizing the relay. An alternator can be connected across leads **10** and **12** to recharge batteries **94** and **104.**

Thus this invention provides a starting and operating control system for a gas turbine engine that greatly improves the probability of a successful start by insuring the presence of fuel in the combustion chamber before engine cranking begins. The system also connects at least two batteries in series across the starter motor during starter motor operation while operating normally on a parallel connection of the batteries.

We claim:

1. In a gas turbine engine having a starter motor, an ignition system and a fuel supply system, said fuel supply system including a fuel pump means for supplying pressurized fuel to a combustion chamber of the engine, a starting control system comprising an electrical energy source, a manual switching means for initiating engine starting, said manual switching means connecting said energy source to said fuel pump means to initiate operation of said fuel pump means, fuel pressure sensing means for sensing when fuel pressure reaches a predetermined value, and a switch means connected to said fuel pressure sensing means for actuating said starter motor when fuel pressure reaches said predetermined value, said electrical energy source comprising a first battery and a second battery, switching mechanism normally connecting said first battery in parallel relationship with respect to said second battery, and switching mechanism connecting said batteries in series across said starter motor during actuation of said starter motor.

2. The engine of claim **1** in which the starting control system comprises ignition circuit means for actuating the ignition system both from the parallel connection of said first battery and said second battery and from the series connection of said batteries.

3. The engine of claim **2** in which the ignition circuit means connects the ignition system in series with said batteries during actuation of said starter motor.

4. The engine of claim **3** in which the starting control system comprises a flame sensing means for sensing the presence of a flame in the engine, and a time delay means for deactuating the starter motor if a flame is not sensed with a predetermined time after a starting cycle is initiated.

5. The engine of claim **4** in which the fuel supply system comprises a solenoid valve connected between said fuel pump means and the engine combustion chamber, said time delay means closing said solenoid valve if a flame is not sensed within a predetermined time after a starting cycle is initiated.

6. The engine of claim **5** in which the fuel supply system comprises an engine driven fuel pump in series with said fuel pump means and a fuel nozzle, said fuel nozzle being located in the engine combustion chamber.

7. The engine of claim **6** comprising an air pump for urging a fuel-air mixture toward an ignitor of the ignition system, said air pump being actuated by a series connection of said batteries during actuation of said starter motor.

8. The engine of claim **1** comprising an air pump for urging a fuel-air mixture toward an ignitor of the ignition system, said air pump being actuated by a series connection of said batteries during actuation of said starter motor.

* * * * *