United States Patent [19]

Porta et al.

[11] **4,425,763**

[45] **Jan. 17, 1984**

[54] **COAL-FIRED STEAM LOCOMOTIVE**

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[73] Assignee: **American Coal Enterprises, Inc.**, Lebanon, N.J.

[21] Appl. No.: **185,601**

[22] Filed: **Sep. 9, 1980**

[51] **Int. Cl.**3 .... **B61B 1/12;** B61B 9/28; F23B 1/10; F28B 7/00

[52] **U.S. Cl.** **60/693;** 60/670; 60/715; 105/37; 105/38; 105/43; 105/46; 105/234; 110/110; 110/198; 110/216; 414/175

[58] **Field of Search** .... 60/653, 670, 677, 679, 60/693, 715; 105/36, 37, 38, 39, 48, 231, 238, 248, 253, 282 P, 43, 48.1, 46, 234; 110/113, 201, 212, 110, 198, 216; 236/14; 241/276; 410/68; 414/175

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Withuhn, "Did We Scrap Steam Too Soon?", Trains, Jun. 1974, pp. 36–48.

"Weer stoomtractie door olieschaarste?" Modelbouwer, Jul. 1978, pp. 280–281.

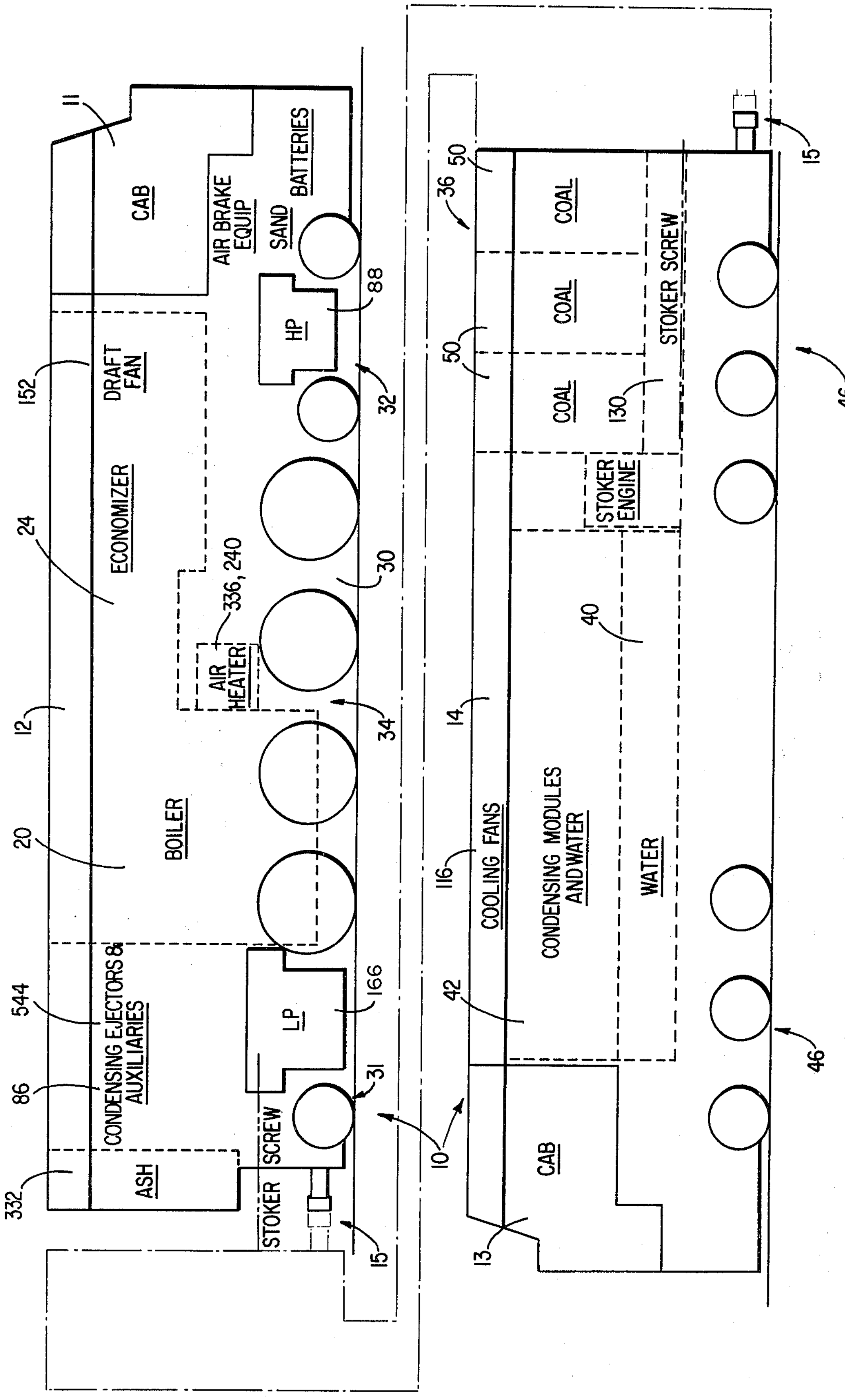
Primary Examiner—Robert B. Reeves
Assistant Examiner—Howard Beltran
Attorney, Agent, or Firm—Fleit, Jacobson, Cohn & Price

[57] **ABSTRACT**

A coal-fired steam locomotive powered by reciprocating steam engines. The locomotive is a two-unit drawbar-coupled locomotive. The units, which are designated as a power unit and a support unit, are arranged back-to-back, with each having a cab-in-front. Operation of the locomotive is equally effective in both directions. The power unit basically contains a furnace and combustion system, an ash storage system, a gas cleanup and exhaust system, a boiler and steam generator, steam engines, a jet condenser, and a control cab. The support unit, on two 6-wheel trucks, contains a modular coal storage area, a stoker motor, a water storage area, heat transfer assemblies and fans for air-cooling circulating

water, and a second control cab. The coal-gasification furnace, steam boiler, and steam engines are all in a closed system. Further, the steam engines of the locomotive are in the form of a four cylinder, balanced system for driving the running gear of the locomotive. The steam expansion cycle is compounded; two high pressure cylinders exhaust into two low pressure cylinders, with all cylinders sized for equal thrust. Spent steam is condensed, cooled on-board, and the water recycled through the boiler. A condensing cycle is utilized to both obtain more power and minimize water make up. A large water supply is carried on the support unit to minimize way side water points. Condensing of the water is by jet condensing which takes place on the power unit and utilizes feedwater as the jet condensing means. The heated water is pumped through a heat exchanger provided on the support unit before returning to the water supply tank. In order to eliminate nusiance dirt, coal is prepackaged in large modules. Up to three modules are placed over the stoker screw mechanism contained on the support unit.

27 Claims, 42 Drawing Figures



11
CAB
AIR BRAKE EQUIP
SAND
BATTERIES
88
HP
152
DRAFT FAN
32
24
ECONOMIZER
336, 240
30
AIR HEATER
34
12
20
BOILER
544
CONDENSING EJECTORS & AUXILIARIES
166
LP
86
31
332
ASH
SCREW
STOKER
15
10
36
50
COAL
COAL
COAL
STOKER SCREW
130
STOKER ENGINE
46
40
14
116
COOLING FANS
CONDENSING MODULES AND WATER
WATER
42
CAB
13

FIG. 1

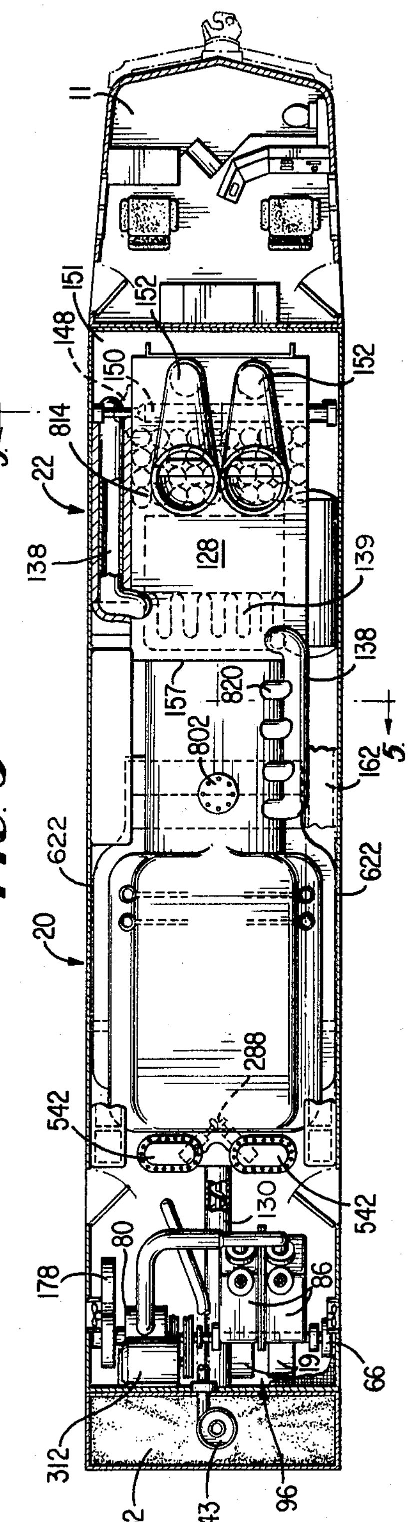
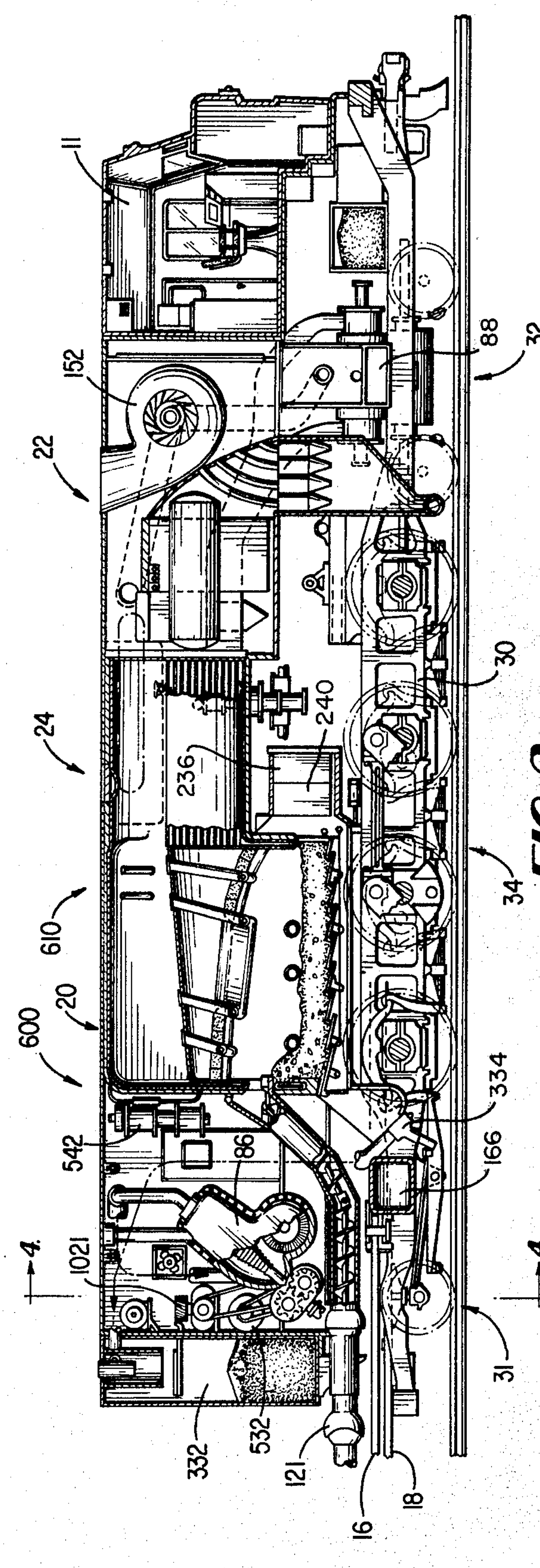

11
151
148
150
152
152
814
5
22
138
128
139
138
157
820
802
162
5
622
622
20
288
542
542
130
80
178
86
19
66
312
332
143
96

FIG. 3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88
32
152
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30
24
240
236
34
610
600
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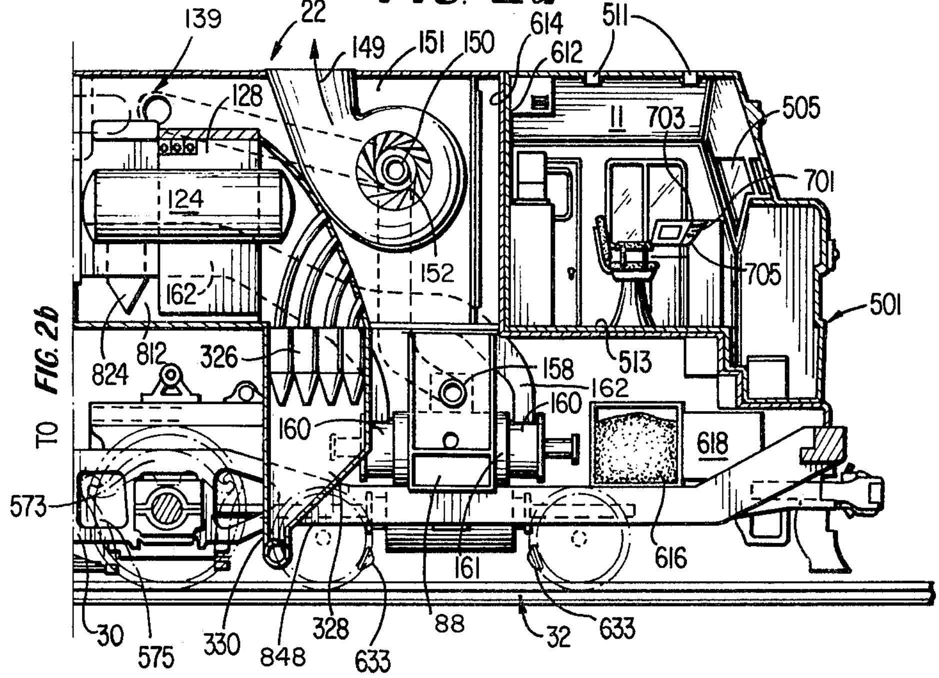
334
542
86
166
4
1021
4
31
332
532
121
16
18

FIG. 2

FIG. 2a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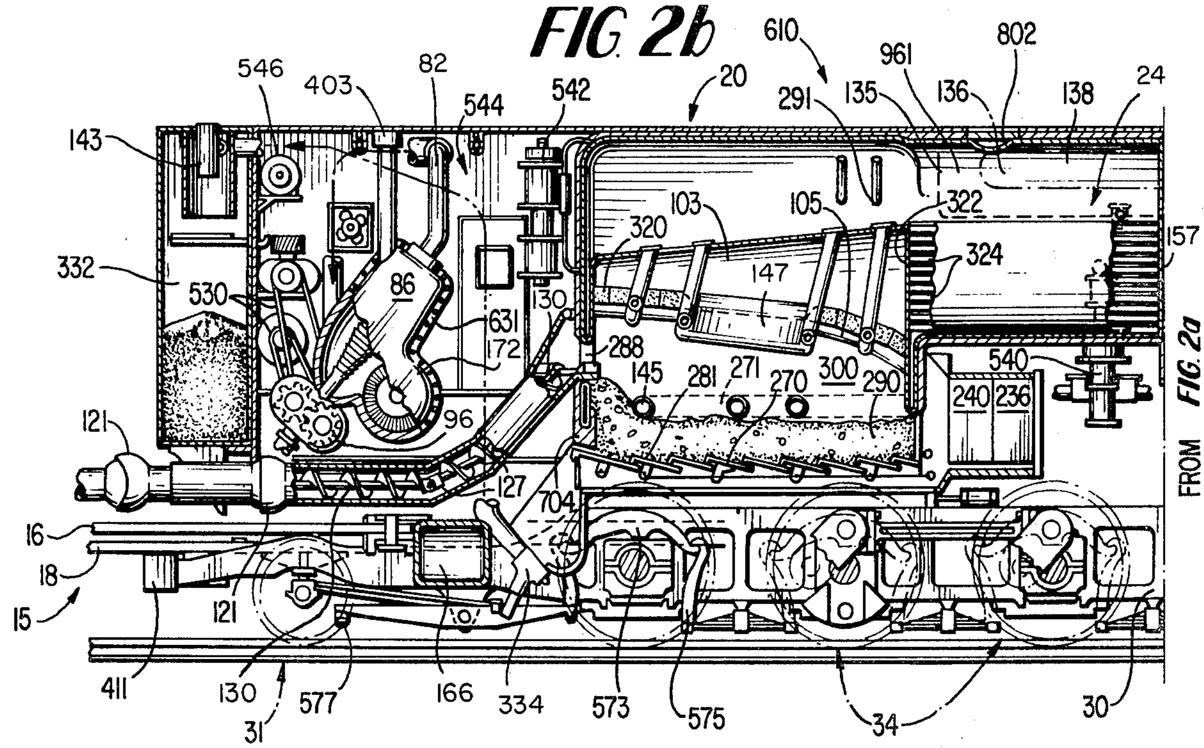
22
149
151
150
614
612
511
505
128
11
703
701
124
152
705
162
501
824
812
326
158
513
162
160
TO FIG. 2b
160
618
573
616
161
30
575
330
848
328
633
88
32
633

FIG. 2b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802
961
24
20
546
403
82
544
542
291
135
136
138
143
322
157
320
103
105
332
530
324
86
147
631
130
172
288
540
145
281
271
270
300
290
240
236
FROM FIG. 2a
121
96
127
704
16
18
15
121
411
130
31
577
166
334
573
575
34
30

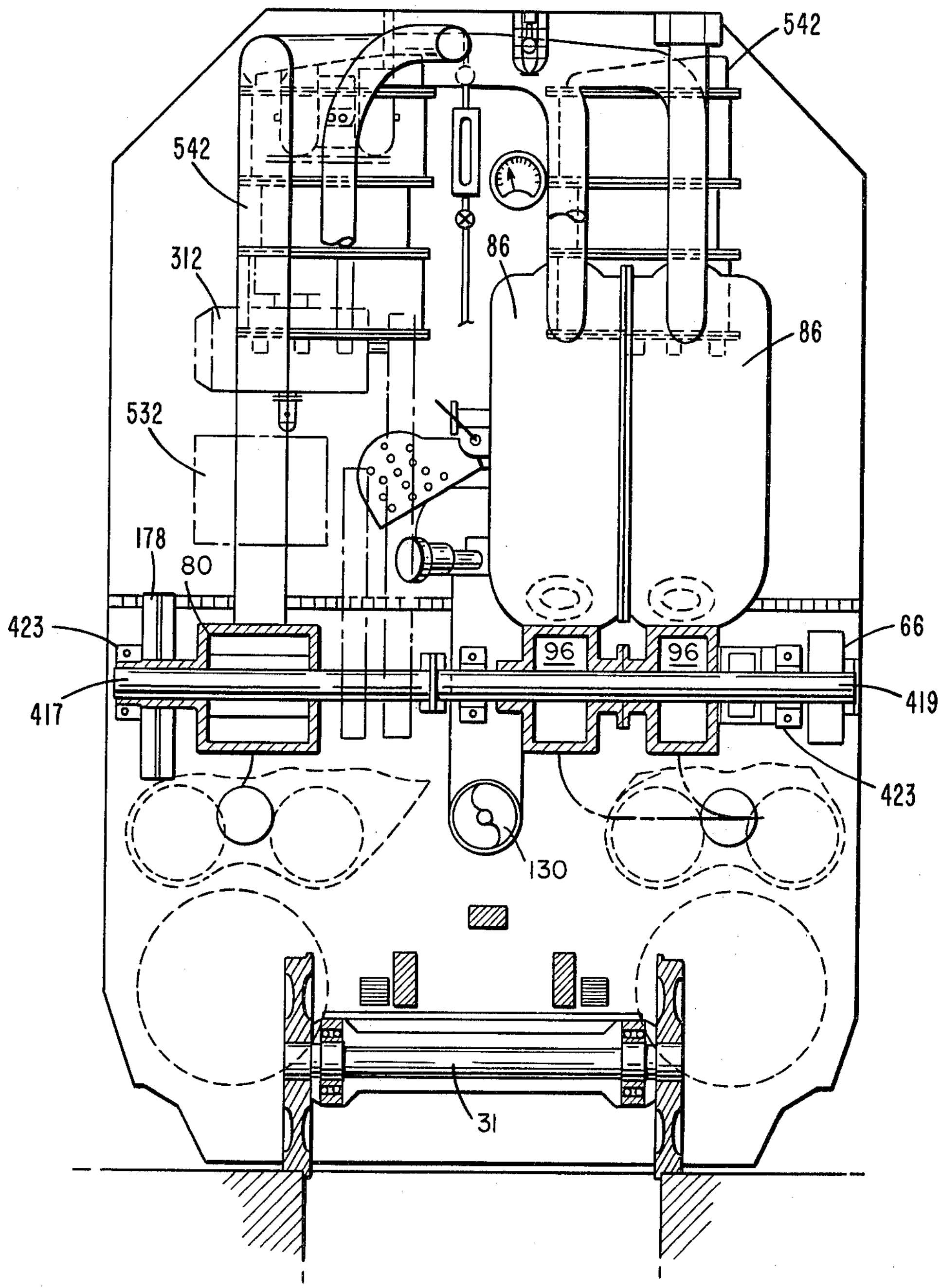


FIG. 4

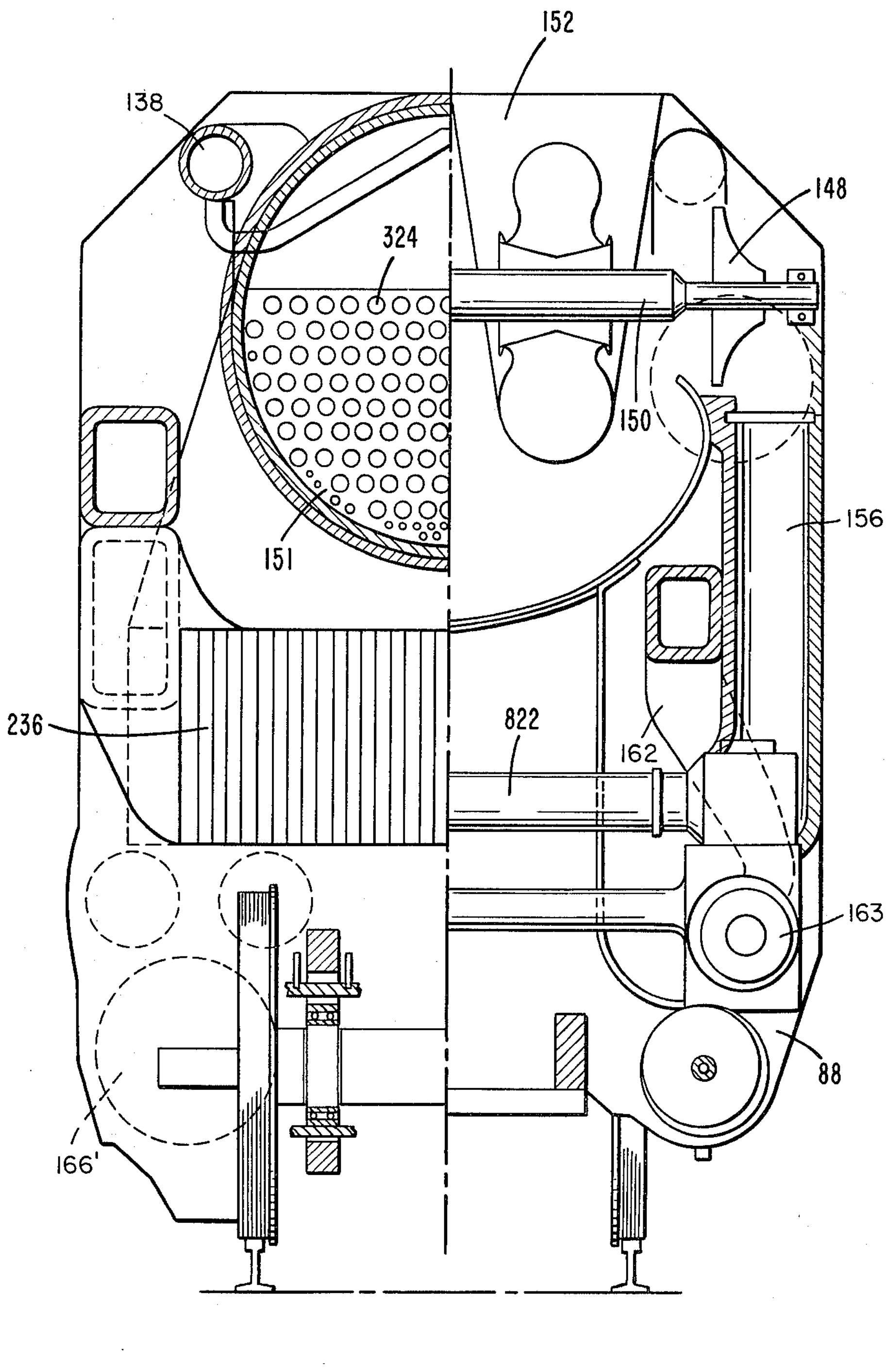
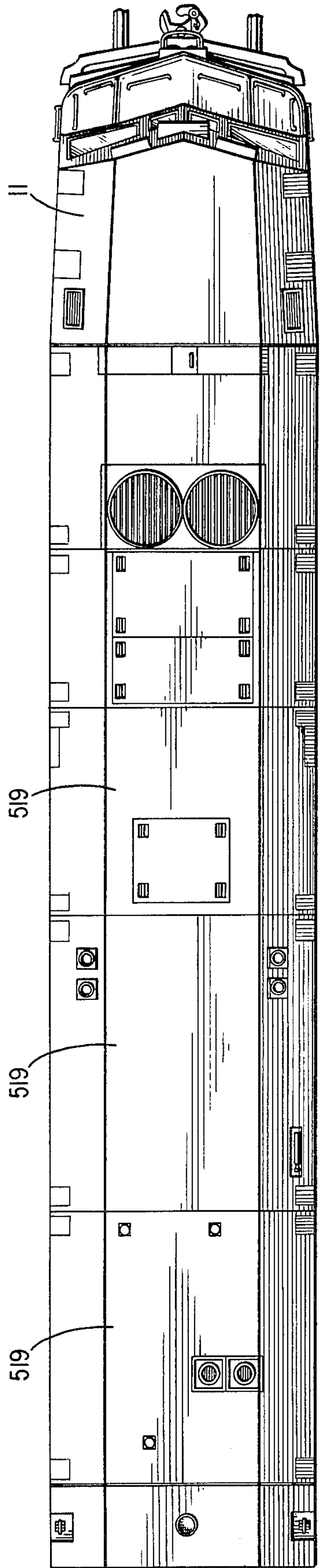


FIG. 5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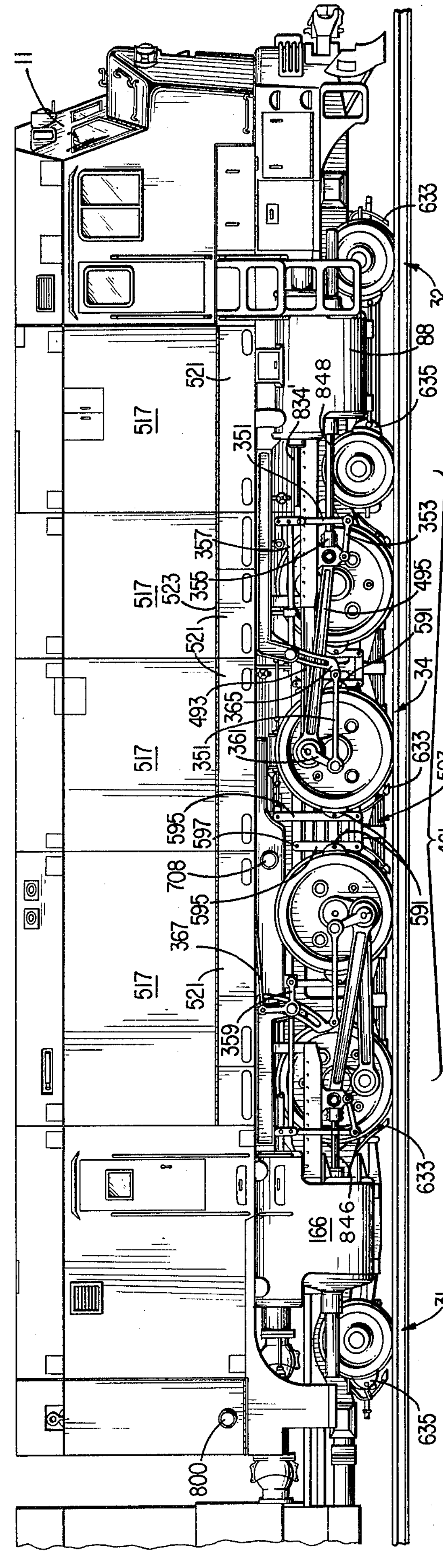
519
519
519

FIG. 7


11
633
32
88
635
848
834'
521
517
351
353
357
517
523
355
495
591
521
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493
365
351
361
633
593
517
595
597
461
708
595
591
367
517
521
359
633
166
846
31
635
800

FIG. 6

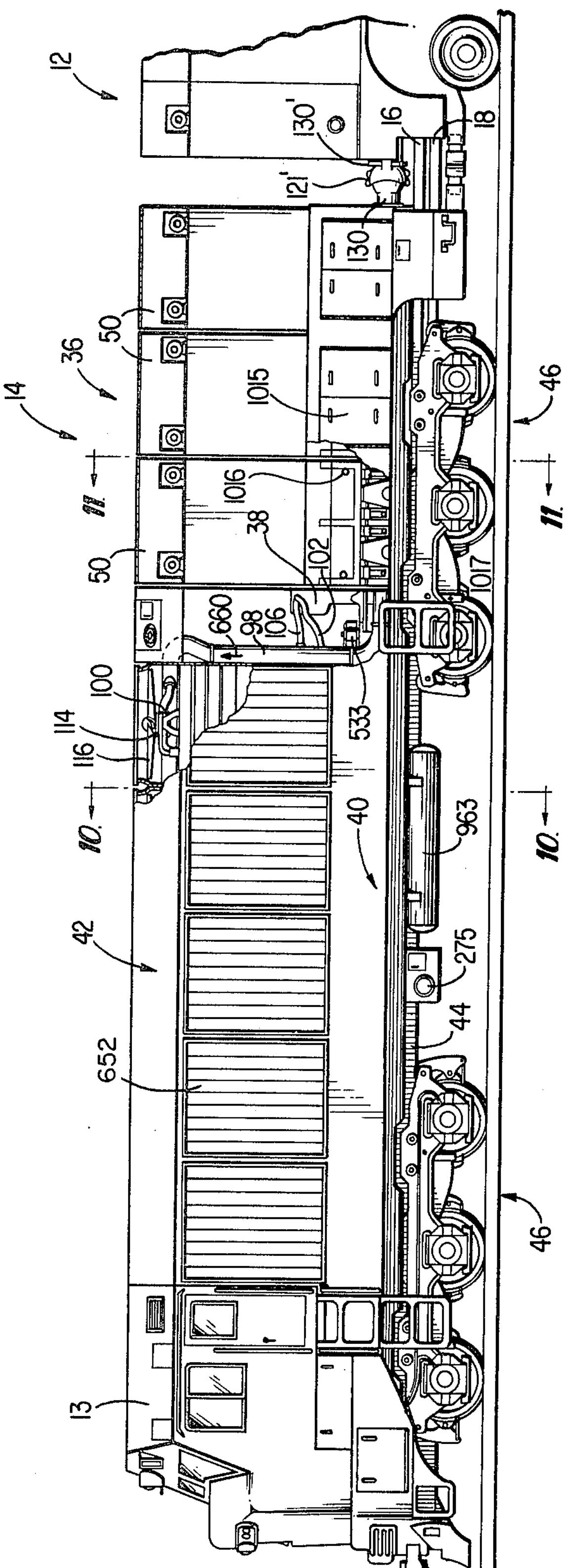
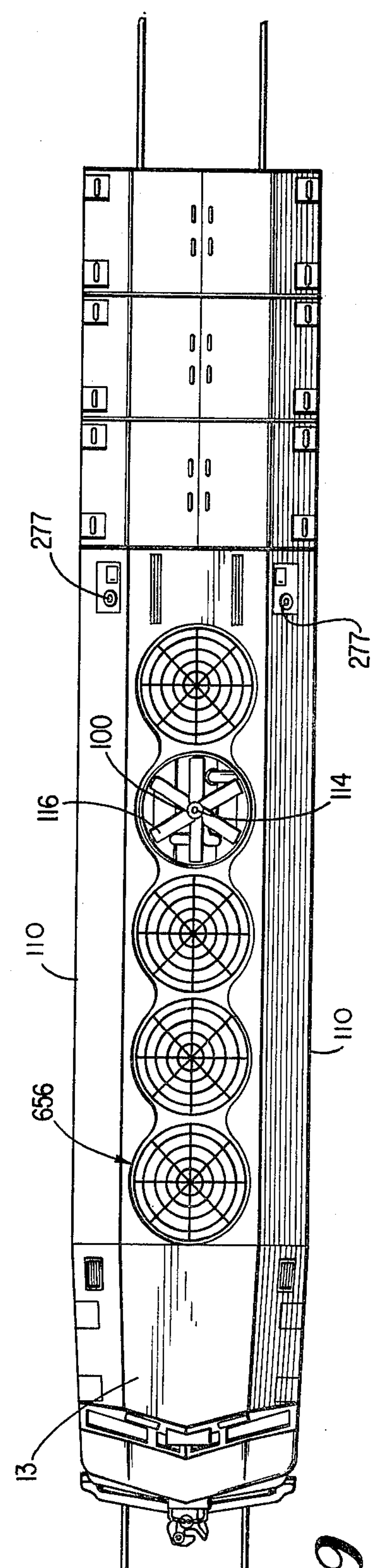

12
130'
16
18
121'
130
50
36
14
1015
46
11
1016
38
102
1017
660
98
106
100
533
114
116
10
40
963
42
275
44
652
13

FIG. 8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100
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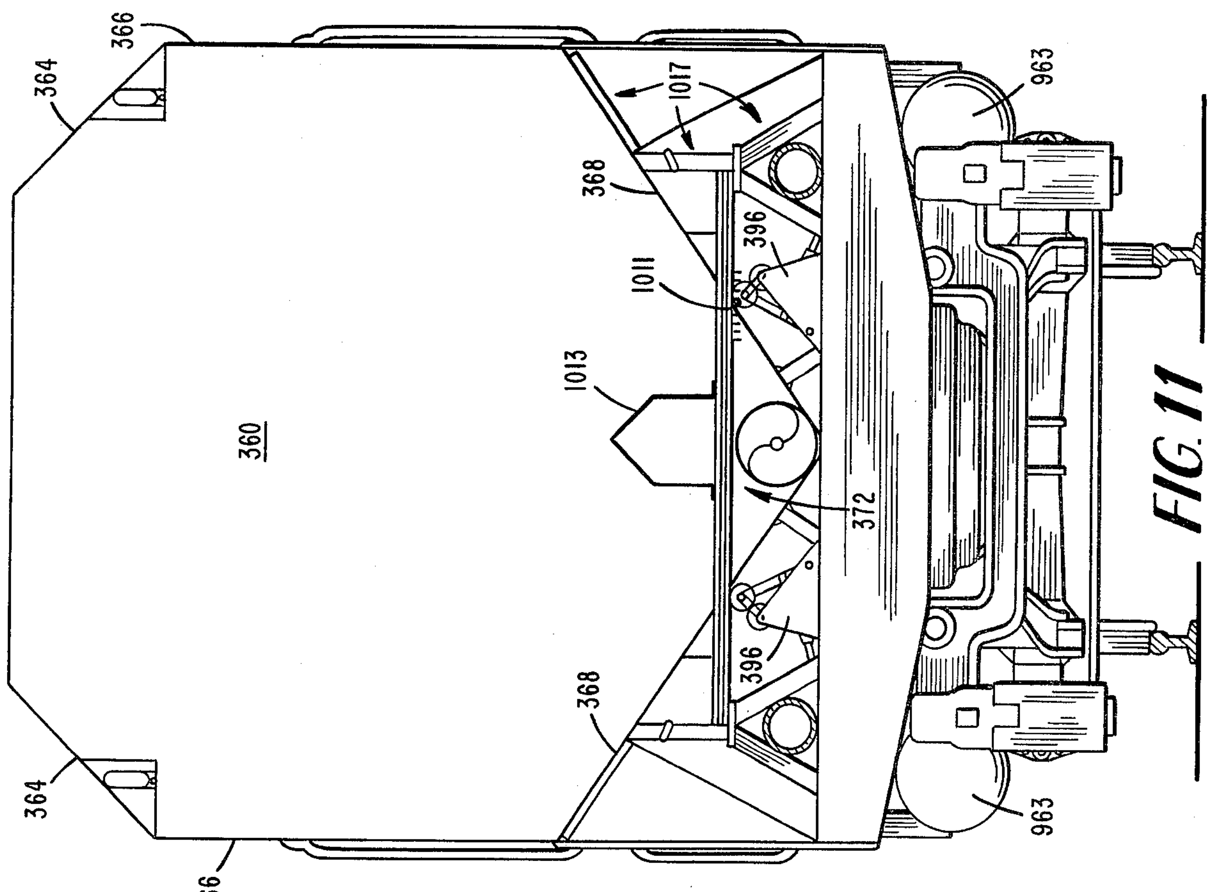
114
110
656
13

FIG. 9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1011
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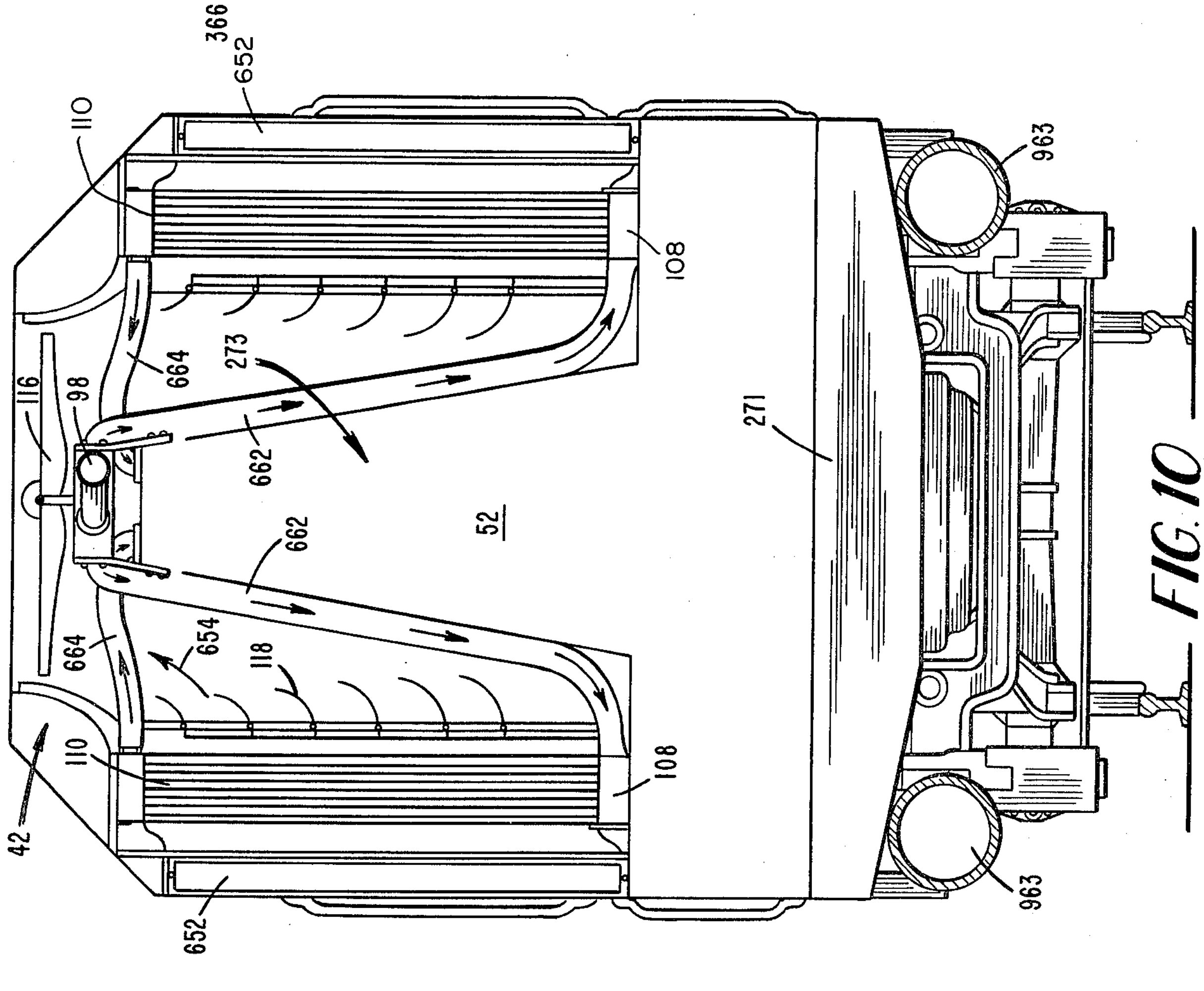
368
364
963
366

FIG. 11


652
110
110
108
116
98
664
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662
271
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662
664
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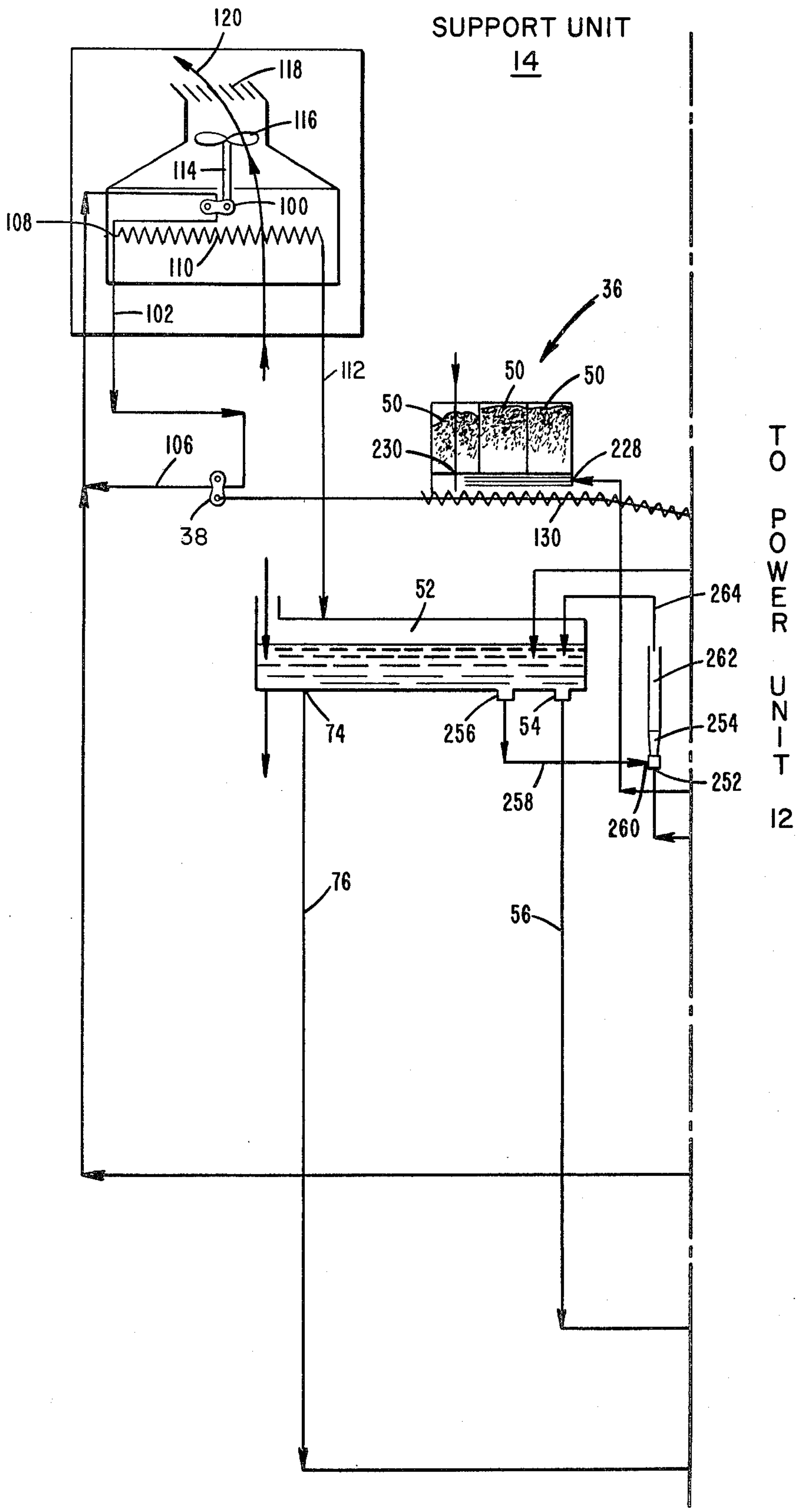
118
110
42
108
652
963
963

FIG. 10

FIG. 12a



SUPPORT UNIT
14
TO POWER UNIT 12
120
118
116
114
100
108
110
102
112
106
38
36
50
50
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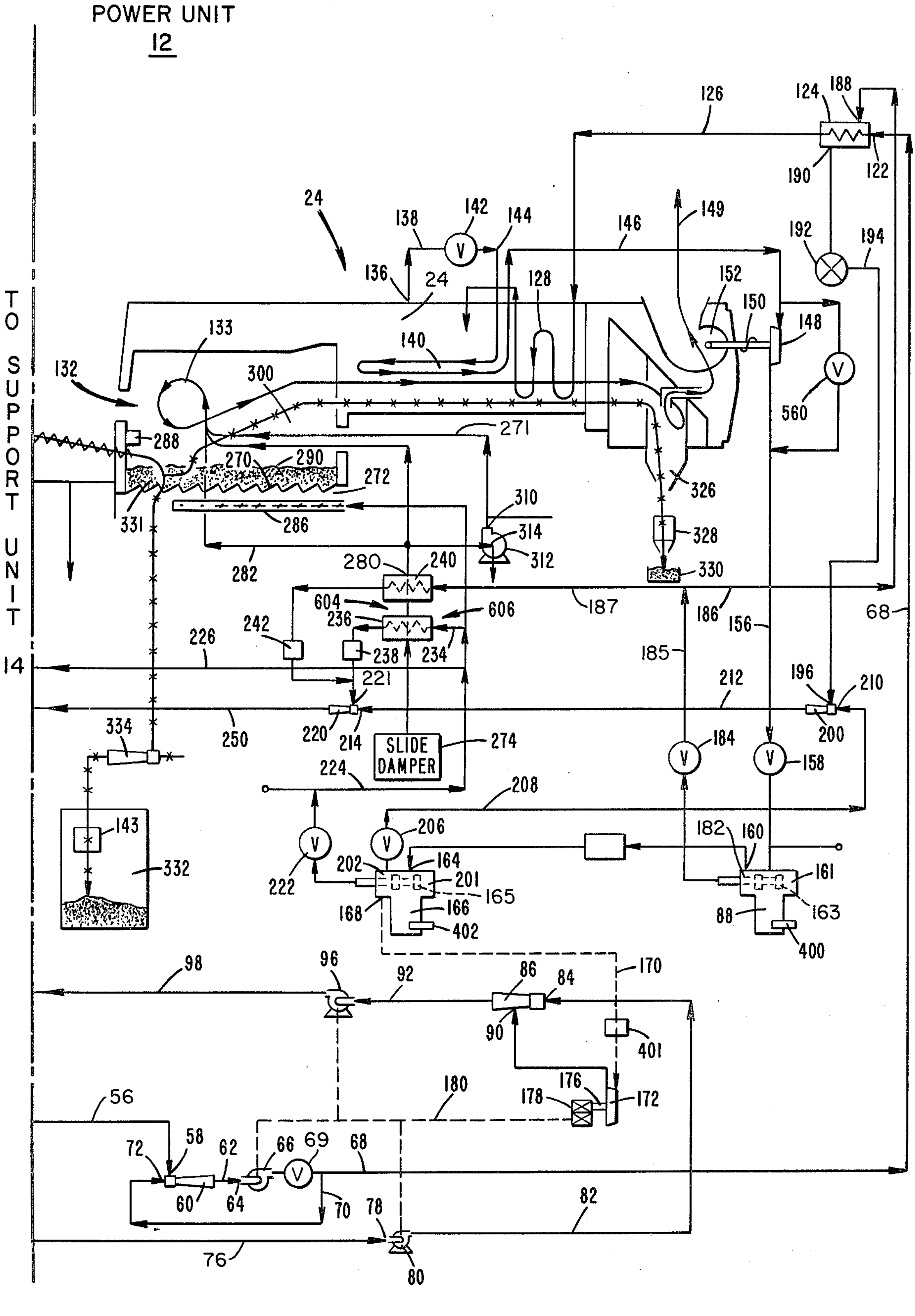
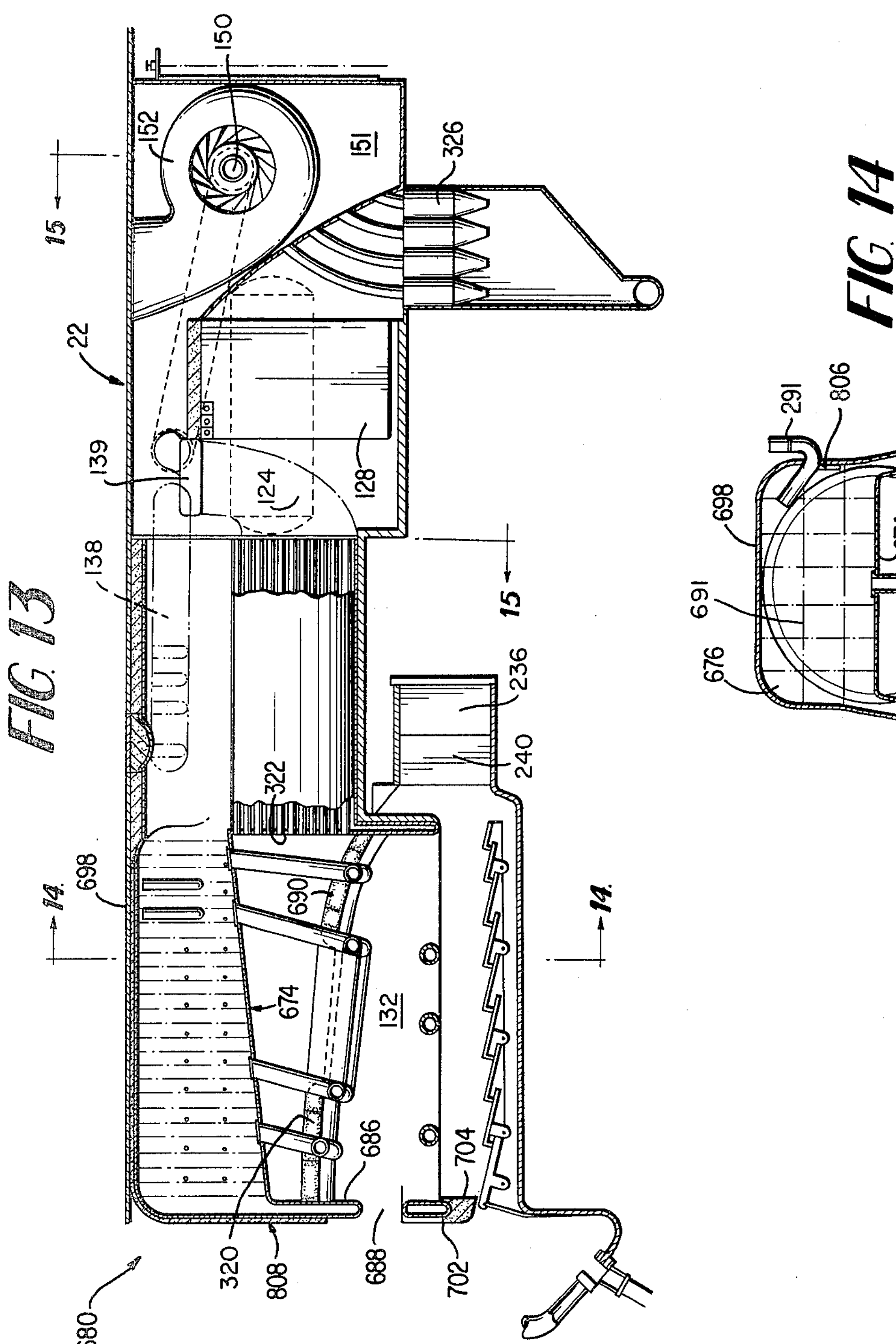
230
228
130
52
264
262
254
252
260
258
256
54
74
76
56

FIG. 12b




150
152
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326
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124
128
138
15
236
240
322
698
14
690
674
132
14
686
704
320
808
688
702
680
291
806
670
694
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698
674
682
688
704
691
676
105
682
704
670
694
702
132

FIG. 13

FIG. 14

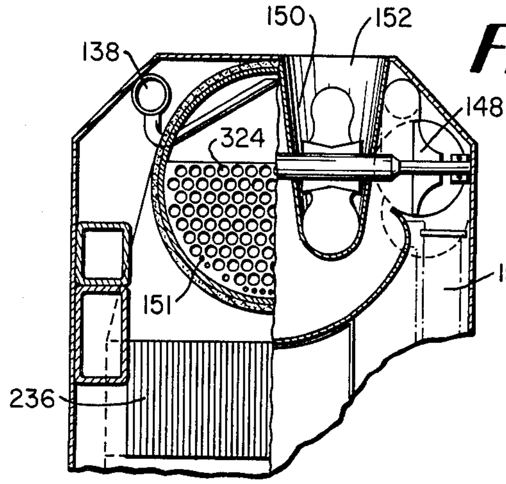


FIG. 15

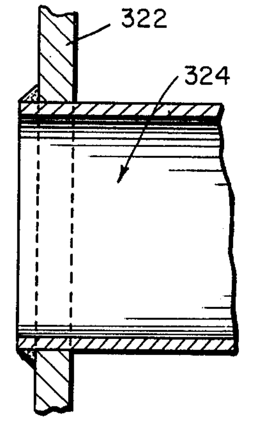


FIG. 16

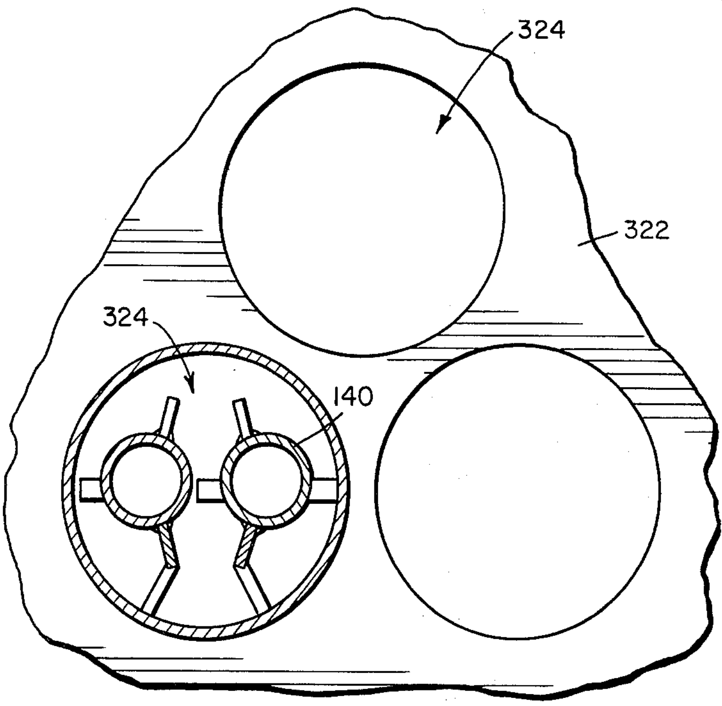
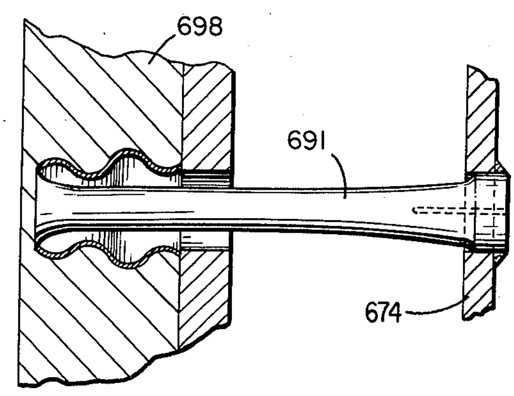


FIG. 17

FIG. 18



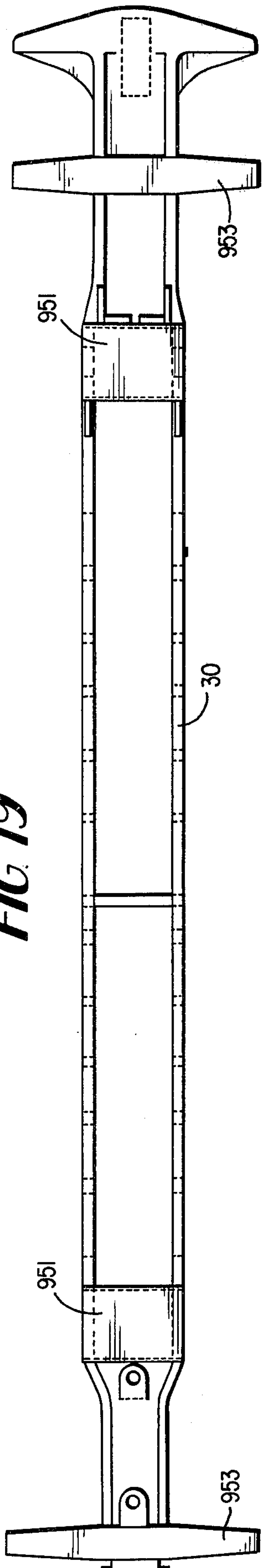


FIG 19

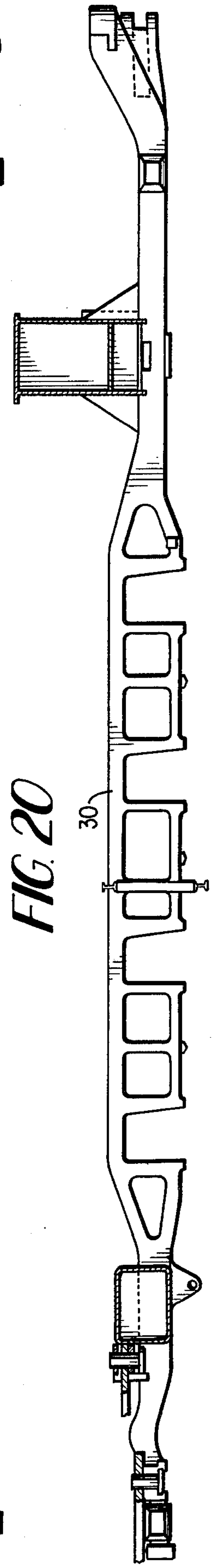


FIG 20

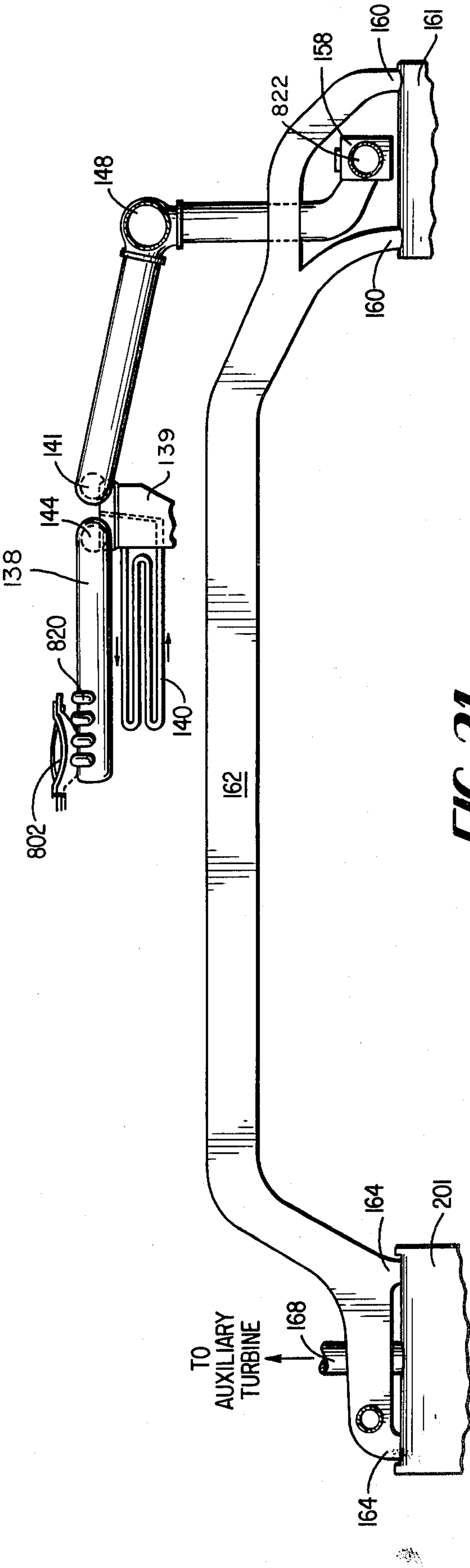


FIG 21

FIG 22a

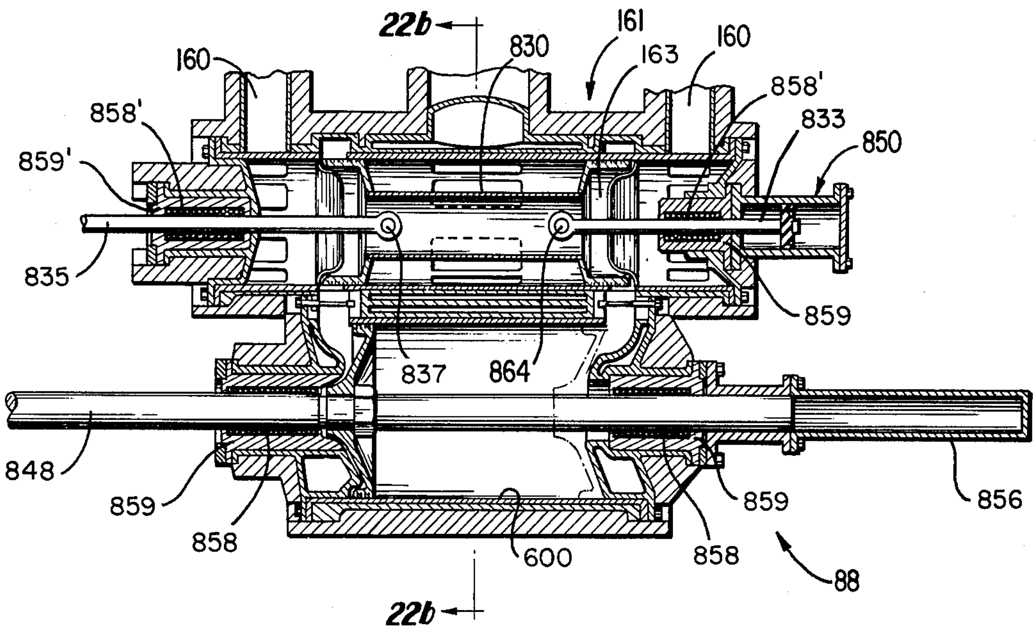
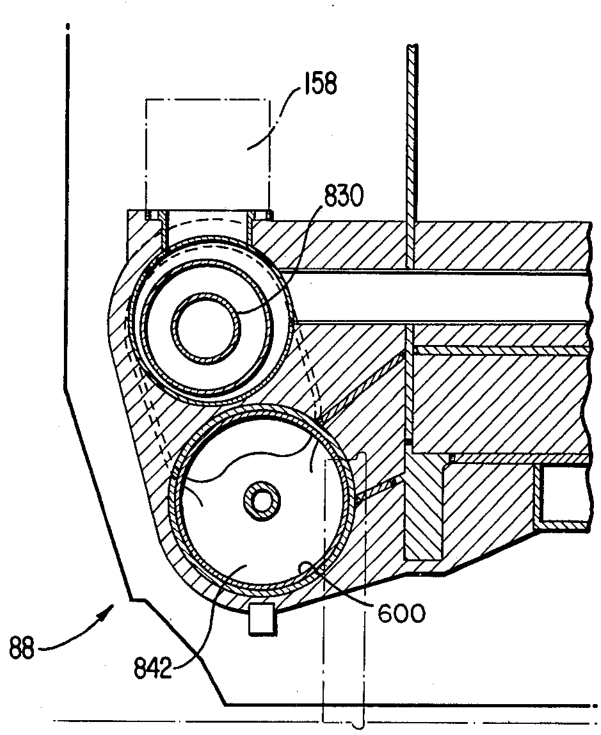


FIG 22b



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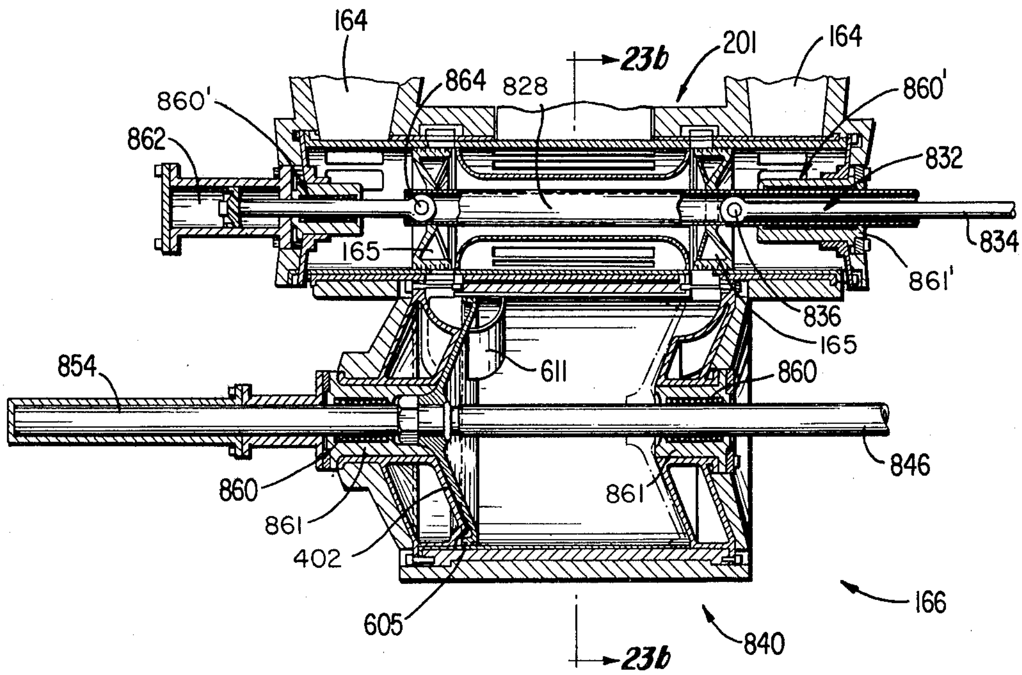


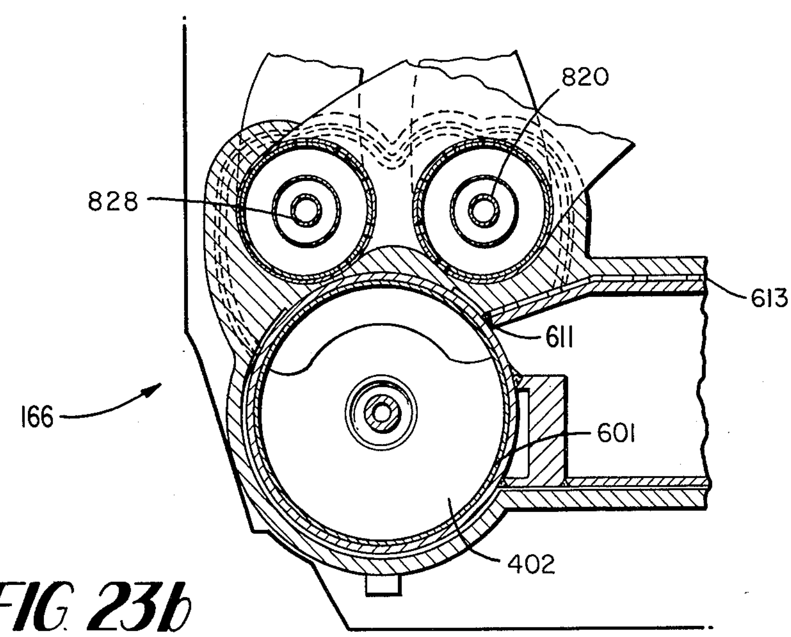


FIG. 23b

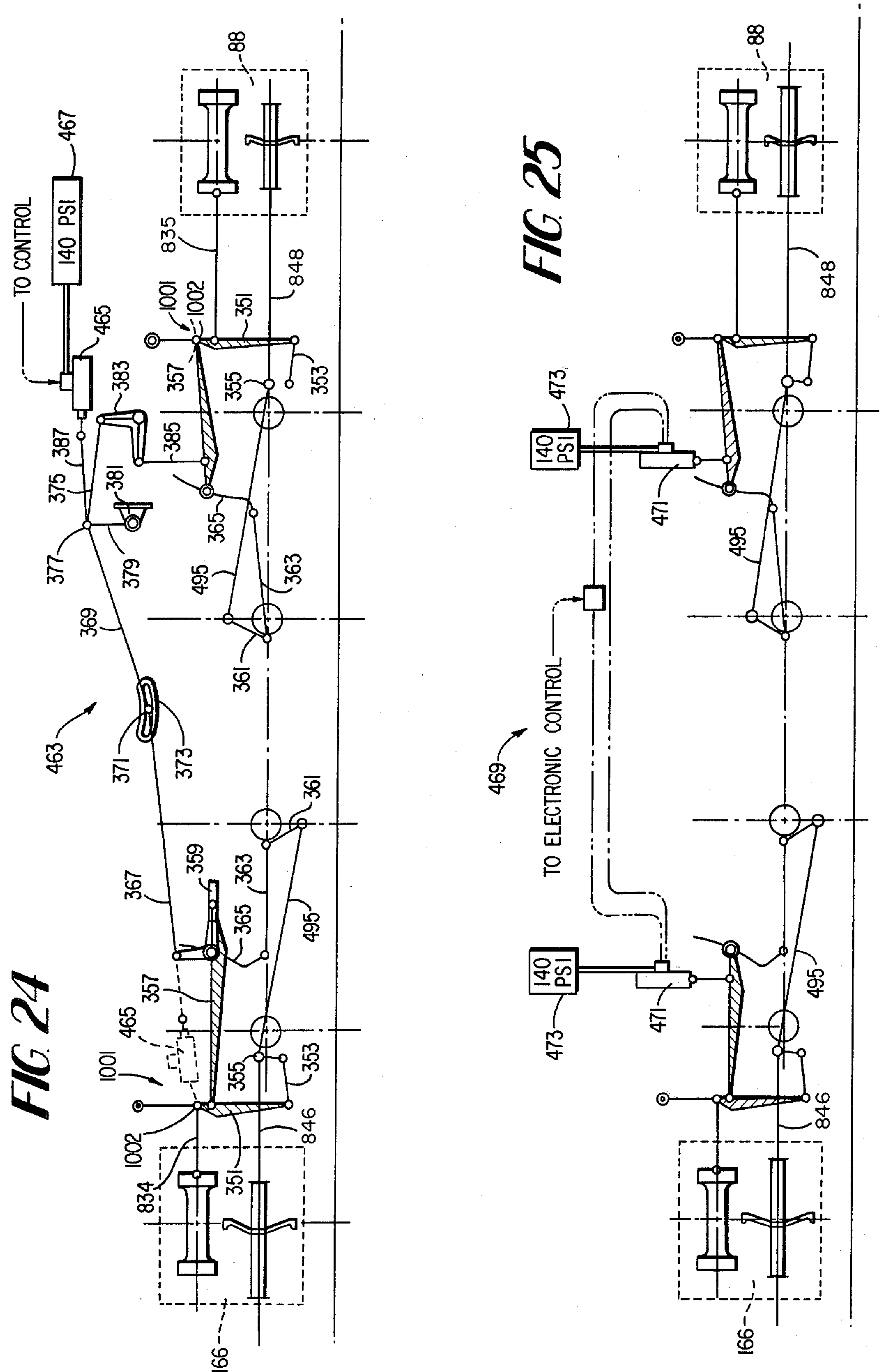


FIG. 24

FIG. 25

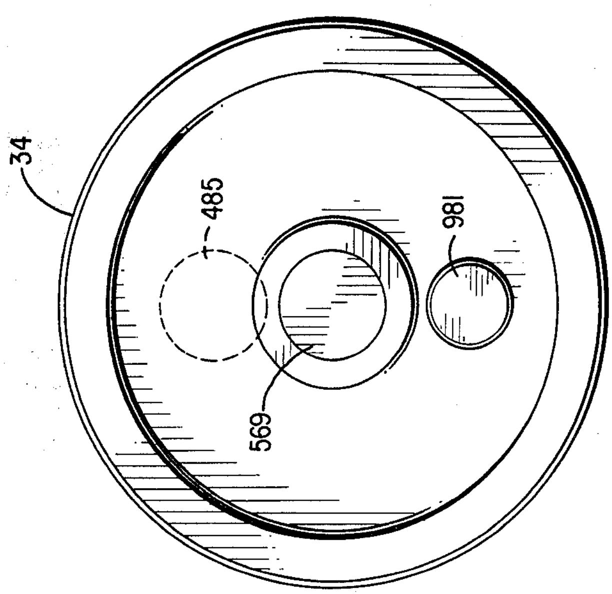


FIG. 27

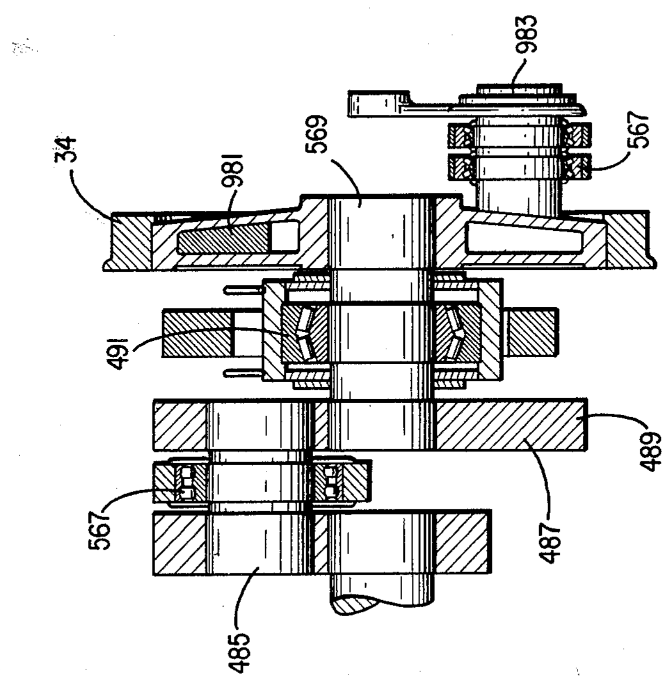
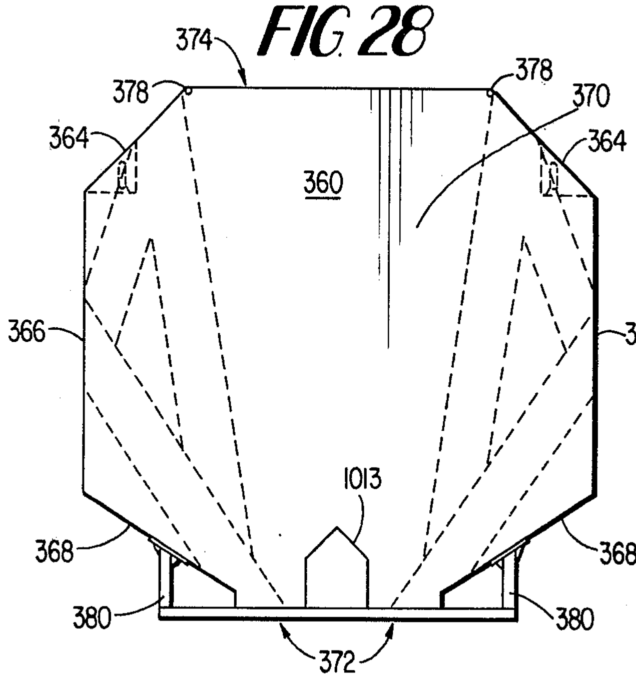


FIG. 26

FIG. 28



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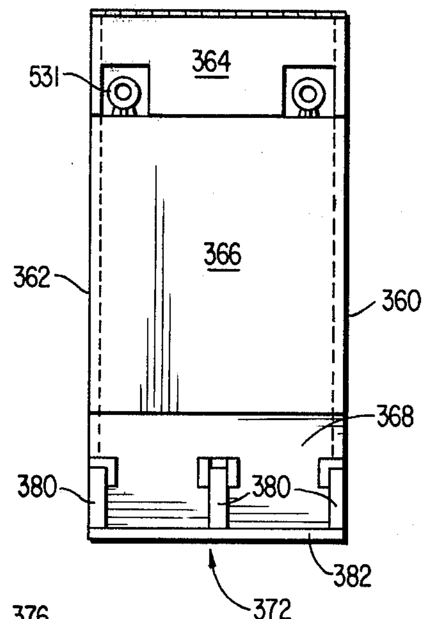


FIG. 30

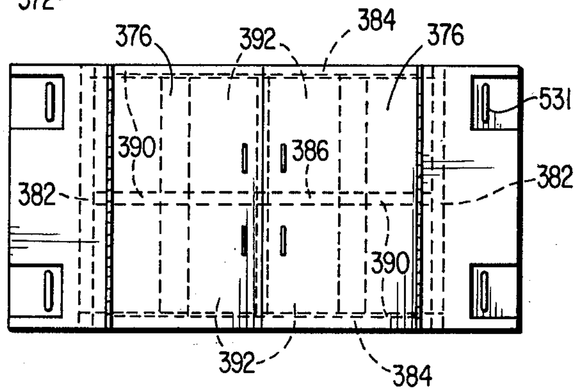


FIG. 31

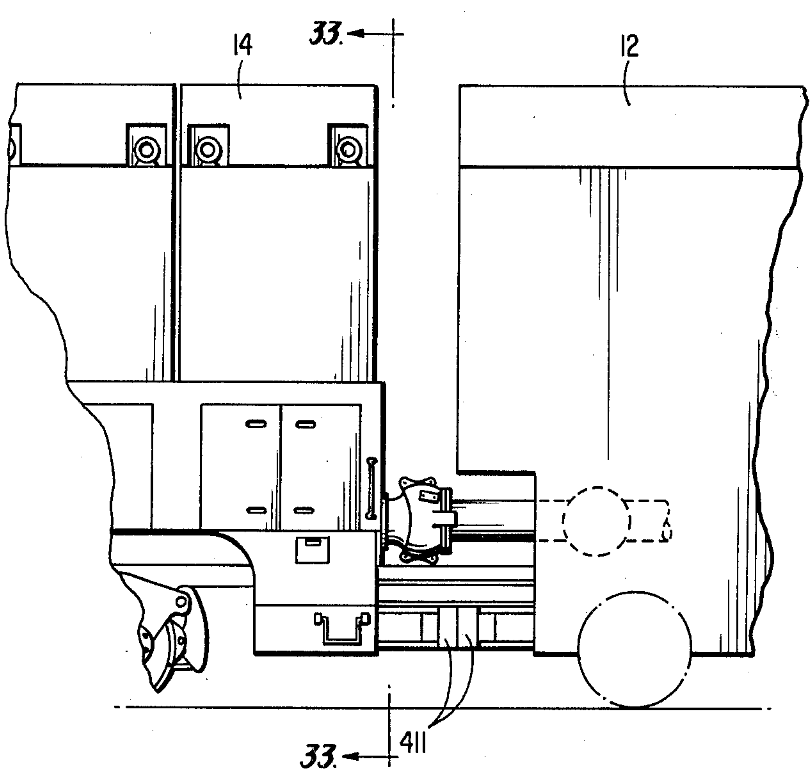
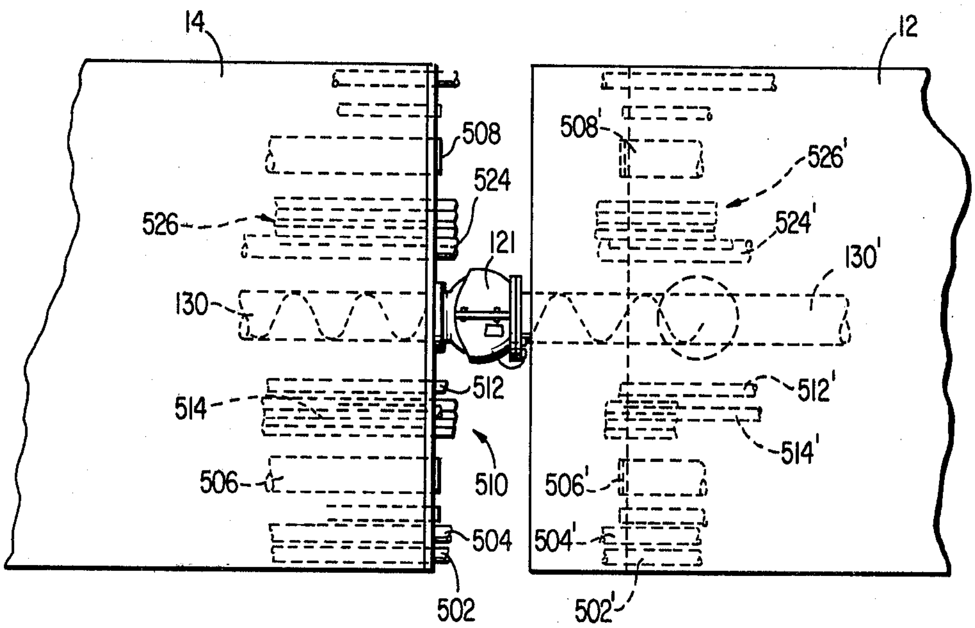
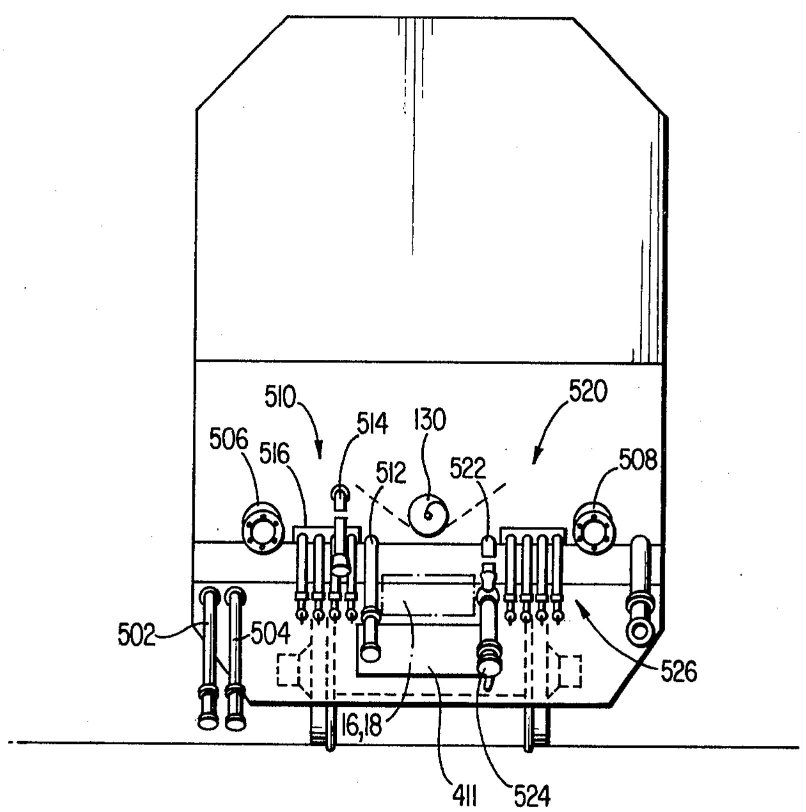


FIG. 32


14
12
508
508'
524
526'
526
524'
121
130'
130
512
512'
514
514'
510
506
506'
504
504'
502
502'


510
520
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130
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522
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502
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526
16,18
411
524

FIG. 33

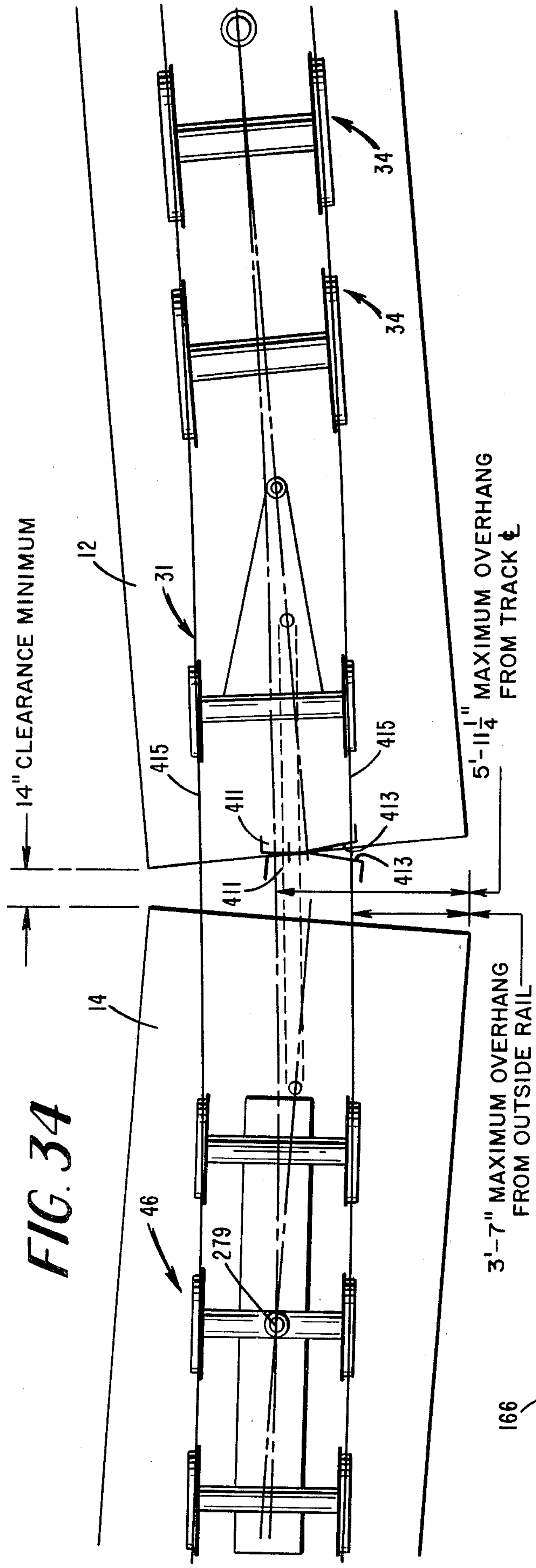
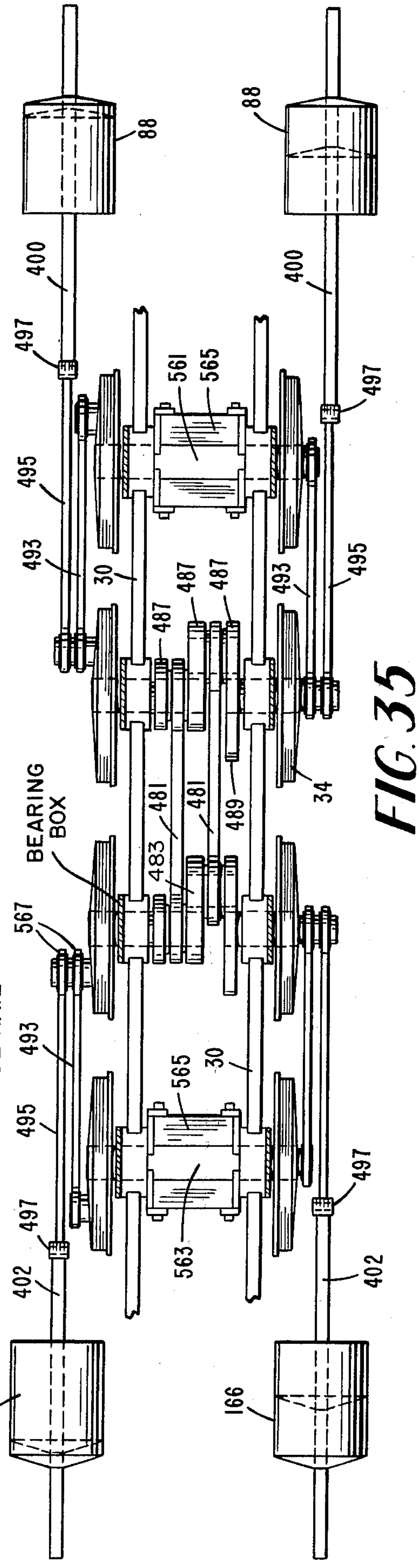

14" CLEARANCE MINIMUM
5'-11 1/4" MAXIMUM OVERHANG FROM TRACK ℄
3'-7" MAXIMUM OVERHANG FROM OUTSIDE RAIL
12
14
31
34
46
279
411
413
415

FIG. 34


BEARING BOX
88
400
402
166
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481
483
489
34

FIG. 35

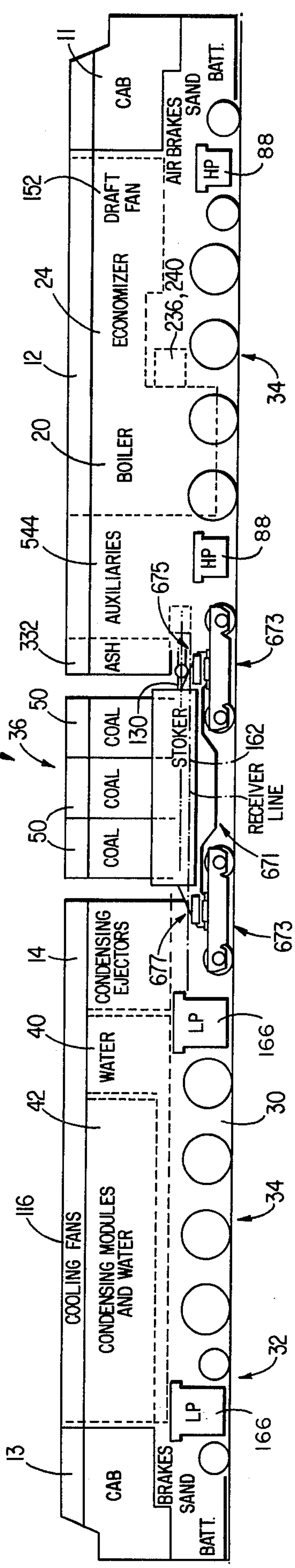
CAB
AIR BRAKES
SAND
BATT.
HP
DRAFT FAN
ECONOMIZER
BOILER
AUXILIARIES
ASH
COAL
COAL
COAL
STOKER
RECEIVER LINE
CONDENSING EJECTORS
LP
WATER
COOLING FANS
CONDENSING MODULES AND WATER
LP
BRAKES
SAND
BATT.
CAB

FIG. 36

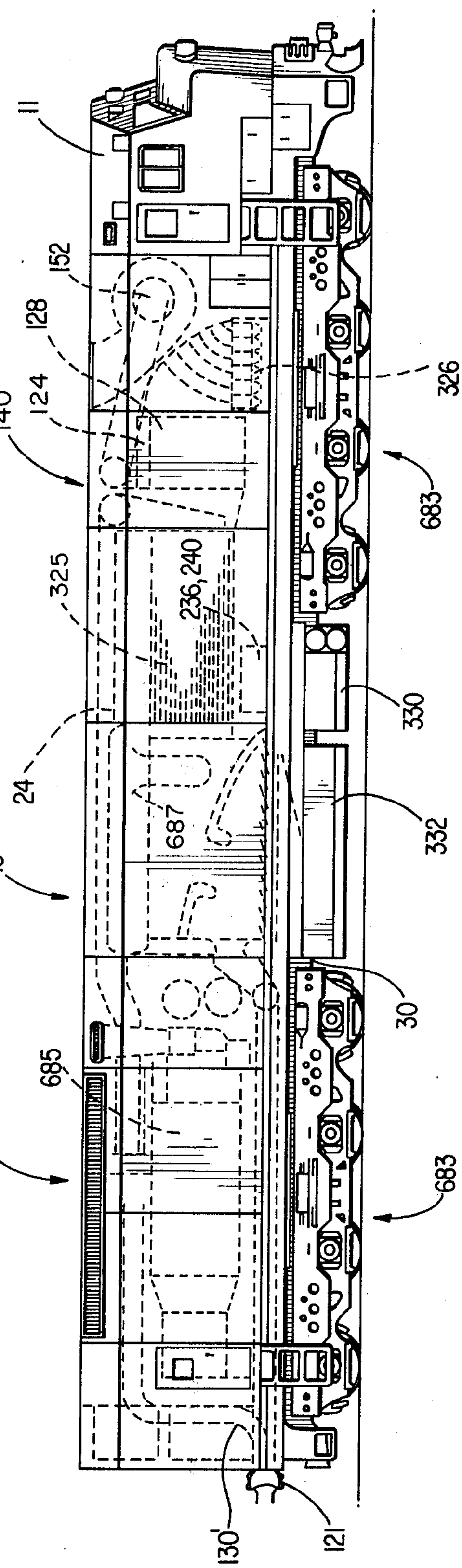

FIG. 37

COAL-FIRED STEAM LOCOMOTIVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to improvements in locomotives and is more particularly concerned with the locomotive which burns coal efficiently and cleanly, and which is compatible with current railroad operating practice.

2. Background of the Prior Art

As a result of the successful introduction of diesel locomotives, the development of coal-fired steam locomotives ceased in the United States in the 1950s. However, steam technology continued to advance in this country and elsewhere, particularly in electric utilities. In a few countries, new designs of railroad steam power in the 1940s and 50s achieved useful fuel efficiencies as high as 12 percent, a level substantially greater than the five to seven percent characteristic of the last U.S. steam locomotives built in any large numbers.

Besides technological advances, other circumstances have changed since the end of steam power on U.S. railroads. Environmental factors such as pollution and noise are now stringently regulated. Railroad operating requirements have changed, and fuel oil prices have increased dramatically.

The basis of most steam locomotives is a noncondensing steam engine of two or more cylinders. In the simpler types of locomotive the cylinders operate with steam at boiler pressure, but in the larger types, the cylinders are often compounded, using the exhaust steam from a set of high-pressure cylinders to power a set of low-pressure cylinders. Steam for the cylinders is provided by a horizontal boiler of the fire-tube type, and the boiler is heated by a firebox or furnace in which coal or fuel oil is burned. After leaving the boiler, the steam is superheated to lessen condensation in the cylinders.

In most U.S. locomotives, steam is admitted to and exhausted from the cylinders by means of slide or piston valves mounted on top of the cylinders. The valves are operated by means of a valve gear which is driven by an eccentric from the driving wheels. Provision is made for the engineer to alter the timing of the valves while the locomotive is in motion to obtain maximum efficiency and maximum power. Some European steam locomotives employ poppet valves instead of slide valves.

The pistons of the cylinders are coupled to the main driving wheel by means of a connecting rod which is fitted to a crank pin on the wheel, and the other drivers are connected to the main wheel by side rods and crankpins. In many cases engines are provided with an additional set of cylinders which operate on the trailing truck of the engine and which are used as "boosters" to give additional power for starting.

On prior locomotives, an enclosed cab is provided at the rear of the engine, behind the boiler and firebox. In this cab all the instruments and controls of the engine are mounted, and at either side are seats for the engineer and fireman. The seats are offset and are provided with windows to give a clear view ahead. The engineer's seat is to the right, and the important controls—throttle, valve-setting controls, and brakes—are grouped on that side of the cab. In smaller locomotives the furnace is hand-fired by the fireman through a fire door in the cab. In large locomotives, the amount of coal used is too great to permit manual firing, and automatic stokers are provided to feed coal to the firebox. In such locomotives the fireman's duties are confined to spreading the coal on the surface of the fire and seeing that the fire burns evenly.

The coal or other fuel used by the engine is carried in a separate tender which is permanently coupled to the rear of the engine behind the cab. The tender carries not only fuel but also water to replace the steam expended in driving the locomotive. In some locomotives the tender is fitted with auxiliary cylinders and acts as a starting booster.

Steam locomotives vary widely in size, power, and design, depending on the uses to which they are put, such as switching, fast passenger runs, or heavy freight hauling. A typical freight locomotive of the steam era had a total weight of 200 tons, of which 130 tons were supported on the driving wheels. Its cylinders had a bore of 25 in. and a stroke of 34 in. Boiler pressure was 245 lb. per sq. in., and the maximum drawbar pull was 64,000 lb. Drawbar pull is the measure of a locomotive's power. A drawbar pull of 1 lb. is, on the average, sufficient to haul a load of 285 lb. on straight, level track. The power required for starting the train is much greater than that needed to pull a moving train. About 1 lb. of drawbar pull is necessary to start a load of 110 lb.

The overall efficiency of a prior art reciprocating steam locomotive was never more than about 8 percent and averaged about 5 percent. Various losses occurred through heat and friction loss of carbon, and an appreciable amount of the steam generated in the boiler was used to operate various auxiliary devices with which most locomotives were equipped. These included pumps for the train's air-brake system, generators, feedwater pumps, rail sanders, stoking devices, and many others.

Beginning about 1940, several U.S. railroads built experimental locomotives powered with steam turbines. In most of these locomotives the turbine was geared down to operate an electric generator which supplied power to driving motors, but in at least one engine, direct drive was used and the turbine was geared to the driving wheels. Operation of these locomotives showed a thermal efficiency greater than that of conventional steam locomotives, but not so high as that of Diesel-electrics.

There is thus a need for an environmentally safe coal-fired, steam locomotive in which heat losses are minimized to improve the overall efficiency of the locomotive, thus providing a viable economic alternative to present day electric and diesel systems. There is also a need for a locomotive which, through employment of modular fabrication techniques, is easily and economically manufactured and serviced. The present invention is directed towards filling those needs.

SUMMARY OF THE INVENTION

The present invention relates to a coal-fired steam locomotive powered by reciprocating steam engines. Its design reflects primary concern for environmental protection and fuel resource conservation. It is a general purpose locomotive, fully compatible with current railroad operating and maintenance practice.

The locomotive is a two-unit, drawbar-coupled locomotive. The units, which are designated as a power unit and a support unit, are arranged back-to-back, with each having a cab-in-front. Operation of the locomotive is equally effective in both directions.

The power unit basically contains a combustion system, an ash storage system, a gas cleanup and exhaust system, a steam generator, a steam engine, an eductor or jet condenser, and a control cab.

In a preferred embodiment, wheel arrangement is 4-8-2, with the leading 4-wheel engine truck providing vehicle guidance when the power unit is in front. Numbers 1 and 4 driven axles have lateral freedom with spring restoration for normal operation on track up to 20-degrees of curvature.

The support unit, on two 6-wheel trucks, contains a coal storage area, a stoker motor, a water storage area, heat transfer assemblies and fans for air-cooling circulating water, and a second control cab.

According to the teachings of the present invention, the steam engine of the locomotive is in the form of a four cylinder, balanced system for driving the running gear of the locomotive.

In a preferred embodiment, the furnace or combustion chamber is arranged in a two stage configuration. Coal is supplied to the primary combustion stage with a stoker screw and spreading means, such as mechanical flippers and/or steam or air jets, to evenly cover the burning fuel bed. Heated air and steam, produced in the steam boiler, are introduced under the grate contained in the lower combustion space, in proper proportion to gasify the coal.

As the gases rise above the fuel bed of the moving or shuffling grate, they are supplied with additional air to sustain ignition and complete combustion. This secondary air is supplied multicyclonically in order to obtain intimate mixing and a longer flame travel. The ashes produced during combustion discharge continuously by shuffling action of the grate to an ash pan separately located on the power unit. The gases produced during combustion leave the fuel bed and secondary combustion space through an opening in the furnace arch and are introduced into an upper chamber, which is located above the furnace arch. Combustion is completed in the upper chamber before the hot flue gas enters a fire tube convection section.

The firetube convection section contains a number of firetubes which may be a smooth wall of thin inner surface to obtain a more efficient heat transfer to water. In a preferred embodiment, a superheater is additionally fitted within the fire tubes for heat transfer to steam. Following the superheater area, the flue gas is conducted into a rectangular chamber of flue gas plenum, across a sinus tube economizer, and into a multi-cyclone dust collector. The clean gas then enters a turbine driven induced draft (ID) fan for exhaust to atmosphere.

Water is stored in the support unit storage tank, and delivered by gravity to a booster injector to provide positive suction head, and then to a boiler feedwater pump. The feed pump is driven directly from an exhaust steam turbine shaft; pump speed is self-regulated in proportion to steam flow. A flow control valve downstream of the pump provides feedwater trim control. Boiler feed is pressure delivered to a feedwater heater (heated by extraction steam from the high pressure cylinder), then to the economizer and to the boiler water space as required to maintain the proper water level.

Steam from the boiler is collected in a dry tube and delivered to the superheater header. Each superheater tube has two loops in series, one in each of two firetubes. Steam is returned to the superheater outlet header, then flows through the induced draft (ID) fan turbine, then through throttle valves before entering the high pressure engine valve chest of each of two high pressure cylinders. A Weiss port in each of the high pressure cylinders supplies extraction steam to the feedwater heater and combustion air preheater. Most of the high pressure steam passes through the piston valves from the valve chest into the high pressure cylinders where it acts on the pistons, thus, converting the thermal energy of the steam into useful work which drives the locomotive. Steam exhausting from each of the high pressure cylinders passes through a receiver pipe, and then into a low pressure engine valve chest of one of two low pressure cylinders, one being associated with each of the receiver pipes. A Weiss port in each of the low pressure cylinders supplies extraction steam for undergrate steam injection and combustion air preheating. Extraction steam condensate from both air preheaters and feedwater heater is returned to the water tank through injectors. Most of the low pressure steam passes through the piston valves into the low pressure cylinders where it acts on the pistons which drive the locomotive.

Steam exhausting from the low pressure cylinders passes through a pair of low pressure exhaust turbines on a common shaft and into a pair of eductor condensers where steam is condensed to water by intermingling with recycled tank water. The water jet into the eductor condensers is propelled by a first water circulation pump, which is driven directly from the exhaust turbine shaft. A second water circulation pump, which is also driven directly from the exhaust turbine shaft, draws suction from the eductor condensers and delivers high pressure water to the support unit to power water turbines for driving cooling fans and the coal feed screw. All water delivered by the second water circulation pump is finally discharged into heat exchangers as cooling coils transferring heat from the water to ambient air, and then drained back into the water tank.

A condensing cycle is utilized to both obtain more power and minimize water make up. A large water supply is carried on the support unit to minimize way side watering points.

In order to eliminate fugitive dust, coal is prepackaged in large modules. Up to three modules are placed over the stoker screw mechanism contained on the support unit.

Power from the high and low pressure cylinders is applied to four driven axles through a mechanical transmission. Cylinders are arranged in two opposed pairs, and are mechanically coupled through the mechanical transmission such that reciprocating mass is fully balanced. This arrangement permits full rotational balance of all driven axles, as well. Thus, all unsprung weight in the wheels and the connecting rods is dynamically balanced. As a result, rail-vehicle interactions should be smooth and weight of the locomotive is equalized among all locomotive axles.

The steam expansion cycle is compounded; two high pressure cylinders exhaust into two low pressure cylinders, with all cylinders sized for equal thrust. Spent steam is condensed, cooled on-board, and the water recycled through the boiler. Steam and water flow paths have been designed to minimize pressure drops in pipes and frictional losses at bends, corners, and valve openings, in order to improve overall efficiency.

It is thus a primary object of the present invention to provide a locomotive which employs an efficient reliable power source.

It is another object of the present invention to provide a locomotive having a closed cycle steam condensing system.

It is a further object of the present invention to provide a locomotive having a coal furnace of improved performance characteristics.

It is still an object of the present invention to provide a locomotive having a dedicated power unit and a dedicated support unit.

It is yet an object of the present invention to provide a locomotive of modular construction.

It is still another object of the present invention to provide a locomotive employing pre-packaged fuel modules.

It is yet another object of the present invention to provide a locomotive employing modular packages for receiving the products of combustion and the other waste products associated with the operation of the locomotive.

It is still a further object of the present invention to provide a locomotive employing an improved steam engine which includes an improved drive system.

It is yet a further object of the present invention to provide a locomotive which is more economically sound then has heretobefore been possible.

These and other objects will become apparent from the following drawings and detailed description.

BRIEF DESCRIPTIONS OF THE DRAWINGS

FIG. **1** is a schematic illustration of a preferred embodiment of a locomotive according to the teachings of the present invention showing a support unit and a power unit.

FIG. **2** is a predominantly side elevation of the power unit of FIG. **1** with the side covering removed.

FIGS *2a* and *2b*, together, constitute our enlarged view of FIG. **2**.

FIG. **3** is a top plan view of the power unit of FIG. **2** with the top covering removed.

FIG. **4** is a section taken along lines **4—4** of FIG. **2**.

FIG. **5** is a section taken along lines **5—5** of FIG. **3**.

FIG. **6** is a side elevation of the power unit of FIG. **2**.

FIG. **7** is a top plan view of the power unit of FIG. **6**.

FIG. **8** is a side elevation, partially cut away, of the support unit of FIG. **1** with a portion of the power unit of FIG. **1**.

FIG. **9** is a top plan view of the support unit of FIG. **8**.

FIG. **10** is a section taken along lines **10—10** of FIG. **8**.

FIG. **11** is a section taken along lines **11—11** of FIG. **8**.

FIG. **12***a* and **12**together constitute a flow diagram used to explain the operation of the various components comprising the power unit and the support unit of FIG. **1**.

FIG. **13** is a side elevation, partially in phantom, of the furnace and steam boiler of FIG. **2**.

FIG. **14** is a section taken along line **14—14** of FIG. **13**.

FIG. **15** is a section taken along lines **15—15** of FIG. **13**.

FIG. **16** is a section showing a firetube mounted against a tube sheet.

FIG. **17** is a transverse section showing a firetube with a superheater tube mounted therein, the superheater tube being supported on separators.

FIG. **18** is a section showing the mounting of a staybolt in the furnace of FIG. **13**.

FIG. **19** is a top plan view of the support frame of the power unit of FIG. **1**.

FIG. **20** is a side view of the frame of FIG. **19**.

FIG. **21** is a partially schematic view showing the major elements of the main steam piping.

FIG. **22***a* is a sectional view of a high pressure cylinder taken through the plane defined by the valve and piston rods.

FIG. **22***b* is a section taken through lines **22***b*—**22***b* of FIG. **22***a*.

FIG. **23***a* is a sectional view of a low pressure cylinder taken through the plane defined by the valve and piston rods.

FIG. **23***b* is a section taken along lines **23***b*—**23***b* of FIG. **23***a*.

FIG. **24** is a schematic illustration used to explain the operation of one embodiment of the valve gear.

FIG. **25** is a schematic illustration used to explain the operation of another embodiment of the valve gear.

FIG. **26** is a transverse section showing a portion of the elements comprising the drive train.

FIG. **27** is a schematic illustration of one of the drive wheels.

FIG. **28** is a front view of an embodiment of a coal module used on the support unit.

FIG. **29** is a side view of the coal module of FIG. **28**.

FIG. **30** is a top view of the coal module of FIG. **28**, with a bottom view in phantom.

FIG. **31** is a elevation partially cut away to illustrate the interconnection between the support unit and the power unit of FIG. **1**.

FIG. **32** is a top view of FIG. **31** with the hoses being shown in phantom.

FIG. **33** is a section taken along lines **33—33** of FIG. **31**.

FIG. **34** is a schematic illustration used to explain the operation of the radial buffer face when the power unit and support unit negotiate a curve.

FIG. **35** is a bottom plan view showing the drive train.

FIG. **36** is a schematic illustration of an alternative embodiment of a locomotive according to the teachings of the present invention.

FIG. **37** is a schematic illustration of a steam-turbine locomotive embodying the teachings of the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

In describing a preferred embodiment of the invention illustrated in the drawings, specific terminology will be resorted to for the sake of clarity. However, the invention is not intended to be limited to the specific terms so selected, and it is to be understood that each specific term includes all technical equivalents which operate in a similar manner to accomplish a similar purpose.

With reference to FIGS. **1-12**, in general, and FIGS. **2** and **12**, in particular, a generalized description of the complete system will be provided with the realization that the particular structure of the elements mentioned will be described in greater detail hereinafter.

The locomotive generally designated as **10** comprises a power unit **12** and a support unit **14**. The units are connected by a coupling system **15**, comprising a draw bar assembly **18** and a safety bar assembly **16**.

Basically, the power unit contains the furnace and combustion system **20**, the gas clean-up and exhaust system **22**, boiler and steam generator **24** and the steam engines in the form of a pair of high pressure cylinders **88** and a pair of low pressure cylinders **166**.

The power unit **12** is arranged on a frame **30** which is supported on a wheel arrangement in a 4-8-2 configuration. The leading four wheels are in a four wheel engine truck assembly **32** which provides guidance for the power unit when the power unit is moving in a forward direction. The eight wheel arrangement **34** constitutes the drive wheels for the locomotive. The power unit, also, has a cab **11** in front.

The support unit **14** basically comprises the coal storage area **36**, the stoker motor **38**, the water storage area **40**, and the cooling assembly **42**. The support unit is supported on a frame **44** which is mounted on two six wheels trucks **46**. The support unit, also, has a cab **13** in front.

Fuel in the form of coal is carried on the support unit **14** in three modular coal packs **50**. In a preferred embodiment, each pack **50** holds approximately 11 tons of two by one-quarter inch run-of-the-mine coal.

Water, about 10,000 gallons, is stored on the support unit in a water tank **52**. Tank **52** contains an outlet **54** connected to a pipe **56** which terminates at an inlet **58** of a suction booster injector **60** on the power unit. The output of the booster injector travels through conduit **62** to the inlet **64** of a feedwater pump **66**. As will be explained in greater detail hereinafter, the feedwater pump **66** is driven by exhaust steam.

A portion of the output of feedwater pump **66** travels through a return conduit **70**, and is fed into a second inlet **72** of the suction booster injector **60**.

The water tank **52** contains a second outlet **74** which is connected to a conduit **76** that provides a cooling water line. Conduit **76** takes cooling water from the water tank and directs it to the input **78** of a water circulation pump **80**.

The output of the first water circulation pump **80** is directed by a conduit **82** to an inlet **84** on each of a pair of eductor condensers **86**. Steam from the exhaust steam turbine **172** is received at a second inlet **90** on each of the eductor condensers **86** in a manner to be described in greater detail hereinafter. The output of each eductor condensor **86** is fed through a conduit **92**, forming a cooling water return line, to an inlet **94** on each of a pair of second water circulation pumps **96**. The output of these pumps is fed through a conduit **98** which defines a cooling water line.

Water flowing in the cooling water line **98** on the support line **12** powers a series of five hydraulic motors **100**, and then passes through a conduit **102** to a hydraulic stoker drive **38** in the form of a hydraulic motor. Water passing through the stoker drive **38** returns to the cooling water line **98** via conduit **106**. A tap **108** is provided in conduit **102** to allow a certain portion of the cooling water to pass through an array of heat exchangers as cooling coils **110** and then into the water tank **52** via conduit **112**.

The hydraulic motors **100** each operate a shaft **114** which rotates a cooling air fan **116**. Rotation of the fan draws cooling air across the cooling coils **110** and out the top of the support unit through a series of deflecting vanes **118** in a manner generally shown by arrowed line **120**.

Returning now to feed pump **66**, a portion of the output of the pump is conveyed on conduit **68** to an inlet **122** of an exhaust steam feedwater heater **124**. Heated water emerges from the feedwater heater and travels through conduit **126** into a fin tube economizer **128** after which it is introduced into the steam generator **24**.

Returning now to the coal storage area **36** on the support unit, coal from each coal package unit **50** is transported to the furnace **20** on the power unit **10** by way of a stoker screw **130**.

In a preferred embodiment, the furnace **20** is a gas producer type. Within the furnace **20** there is defined a furnace chamber **132** where coal combustion takes place. Since the combustion process within the furnace chamber **132** relies on steam generated by the locomotive system, the details of the combustion process will be delayed until after a discussion of the steam generator has been presented. Suffice it to say at this point that heat is released by combustion in the form of radiant energy and hot flue gas which is introduced into the steam generator **24** to convert the water introduced from the economizer **128** into steam which exits from the steam generator **134** via outlet **136**. Steam appearing at outlet **136** travels through a drytube **138** into a superheater **140**. A pressure reducing and shut-off valve **142** is interposed between the outlet **136** of the steam boiler and the superheater header input **144** of the superheater.

Superheated steam from the superheater **140** passes through a conduit **146** into an induced draft (ID) fan turbine **148**. Connected to the ID fan turbine **148** by a drive shaft **150** is an ID fan **152**, which in a preferred embodiment is a pair of squirrel cage blowers. The steam then exits the ID fan turbine **148** and passes through a conduit **156** into a pair of Wagoner throttles **158**. Each throttle **158** is associated with a high pressure cylinder **88**. The piston valves **163** in the valve chest **161** admit main steam alternately into the front and back of the cylinder, forcing the pistons **400** into a reciprocating mechanical motion.

Each high pressure cylinder **88** contains a pair of Weiss ports **182**. Steam extracted from Weiss port **182** passes through a non-return valve **184** and through conduit **185**. A portion of the steam in conduit **185** passes into a conduit **186** and into the steam input **188** of the exhaust steam water heater **124**. The steam passes out of the exhaust steam water heater **124** via outlet **190** and then through a condensate trap **192**. From the trap the steam travels through a conduit **194** and into the inlet **196** of an ejector **200**.

At the same time, a portion of the high pressure exhaust steam branches off into conduit **187** and passes through a receiver steam air heater **240** and then through a condensate trap **242** after which it merges at the inlet **221** of ejector **220**. The output of ejector **220** travels through conduit **250**, which is a condensate and exhaust steam line, into an inlet **252** of yet another ejector **254** that is on the support unit.

Steam exhausted from outlets **160** of each high pressure cylinder **88** passes to an associated receiver pipe **162** and from there to an inlet **164** of a low pressure valve chest **201** containing the piston valve **165**. The piston valves admit receiver steam alternatively into the front and back of the low pressure cylinder **166** forcing the low pressure pistons **402** into a reciprocating mechanical motion which is coordinated with the motion of the high pressure pistons.

Exhaust steam from each outlet **168** of low pressure cylinder **166** passes through a conduit **170** through an oil separator and into an exhaust steam turbine **172**. There are two exhaust steam turbines **172**, one at each low pressure cylinder exhaust **168** arranged to drive a shaft **176**. This shaft through a speed reduction gear **178** causes the main power shaft **180** to rotate and thereby provide motive power to the feed pump **66**, the first water circulation pump **80** and the second water circulation pump **96**, and an air roots blower **312**.

Each low pressure cylinder **166** also contains a pair of Weiss ports **202**. Low pressure steam exhausting from Weiss port **202** is fed through an associated non-return valve **206** and then through a suitable conduit **208** into an inlet **210** of ejector **200**. The output of ejector **200** is fed through a conduit **212** into an input **214** of a second ejector **220**.

The low pressure exhaust steam from each of the low pressure cylinders **166** passes from the other Weiss port **202** through an associated non-return valve **222** then through a suitable conduit **224** that contains many branches which lead to various parts of the system. A first branch **226** leads from the power unit through a suitable connection to the support unit and provides coal wetting steam at a point **230** where fuel, in the form of coal, is exiting from one of the coal package units **50**. A second branch **234** passes through a steam air heater **236** and then through a condensate trap **238** and finally into an inlet **221** of ejector **220**.

The water tank **52** contains another outlet **256**. Water from this outlet is fed via conduit **258** to an inlet **260** of ejector **254**. The output of ejector **254** travels directly into a water mixer **262** the output of which travels through conduit **264** into the water tank **52**.

Having described the steam production phase of the system, attention is now drawn again to the furnace area **20**.

The furnace basically comprises a furnace chamber **132** in the bottom of which is disposed a shuffling or oscillating grate **270** below which is defined a wind box **272**. Air from a slide damper **274** passes through the low pressure exhaust steam air heater **236** and the receiver steam air heater **240** from which it exits as heated air. At the outlet **280** of air heater **240** the heated air branches off into three directions. One branch in conduit **282** is primary air which is introduced into the wind box **272** below the grate **270**.

A portion of the exhaust steam from the low pressure cylinders **166** as carried by the conduit **224** is introduced into an injector **286** positioned below the grate within the wind box **272**.

As stated before, coal is fed into the furnace chamber by a stoker screw **130**. The coal is distributed by twin ram spreaders **288** or other means onto the grate **270** to define a fuel bed **290**. Combustion within the furnace chamber occurs in two stages. In the first stage, coal burns in the primary air supplied under the grate **270**. This air is insufficient for complete combustion. The products of the first stage of combustion are cumbustible gases which are burned to completion in over fire air region **300** above the fuel bed **290**. This is the second stage of combustion. Gas production is further enhanced by ejection of steam into the under fire air in the approximate mass ratio (steam-to-air) of 1-to-10. This method of combustion results in producer gas which components include hydrogen and carbon monoxide.

The producer gas burns above the fuel bed in the secondary over fire air region **300**. Hot combustion gases move in a cyclonic path **133** as a result of the introduction of a portion of the secondary heated air from the outlet **280** of the receiver steam air heater **240** along with the introduction of swirling air provided at the output **310** of an air turbulator **312**. The input **314** of the air turbulator **312** receives the heated air from the output **280** third branch of the air heater **240**. The air turbulator or air roots blower **312** is mechanically driven by the main power shaft **180** in the manner described hereinbefore.

The hot combustion gases move in a cyclonic path through a furnace arch **320** and through the back tube sheet **322** into the firetubes **324**. The combustion gas or flue gas may also carry with it particulates as it passes through the fire tube **324**. Therefore, the combined mixture of flue gas and particulates are introduced into a gas cleanup and exhaust system **22**. First the mixture enters a battery of cyclonic dust collectors **326** for gas clean-up. The cyclonic dust collectors **326** discharge the particulate into a separator or hopper **328** from which the contents are deposited into a pan **330**, which is of modular construction and easily removed for dumping.

After separation, the flue gas escapes from the collectors **326** and is released to atmosphere after passing through the pair of draft fans **152**.

During combustion of the coal in the furnace **132**, ash is produced. The shuffling movement of the grate **270** causes the ash to be passed to an ash pan **331**. The ash pan **331** is periodically cleared by a steam jet which transports the ash to a cyclone separator **143** and then into an ash package **332** removably mounted on the back of the power unit **12**. The ash from the grate is introduced into the ash package **332** with the aid of a steam ejector **334** in order to confine fugitive dust during ash ejection.

Having completed a general description of the elements constituting the locomotive system, the specific details of those elements will now be described.

With reference to FIGS. **8-11**, the details of the support unit **14** will be presented.

The support unit **14** basically comprises a frame **44** which is supported on two six wheel trucks **46**. Near the right-side portion **350** of the support unit is defined the coal storage area **36**. In a preferred embodiment, three removable coal package units **50** constitute the coal storage area.

With reference to FIGS. **11** and **28-30**, the details of one modular coal pack **50** are shown. The coal pack **50** is a slender structure defined by a front wall **360** a back wall **362** each of which is configured to meet AAR clearance standards. As shown in FIG. **28** walls **360** and **362** are generally octagonal in shape, although other shapes are contemplated. The two walls are generally normal to the frame **44** and are spaced coterminously from each other. Two top side walls **364**, two middle side walls **366**, and two bottom side walls **368** are joined to a portion of the periphery of front wall **360** and back wall **362** to define a volume **370** for receiving coal. This wall structure also defines a bottom opening **372** through which coal may pass to the coal stoker and a top opening **374** through which coal may be introduced during loading. A pair of hinged doors **376** which are secured by transversed hinges **378** provide a cover for the top opening **374**.

Disposed transversely along each bottom side wall **368** are three equally spaced outwardly extending members **380**. Secured to the distal ends of these members is a transversely extending frame member **382**.

On either side of the bottom opening **372** along the edge defined by forward wall **360** and back wall **362** are a pair of members **384** whose ends are welded to the ends of members **382**. Disposed between members **384** is an elongated frame member **386** whose ends are joined to the mid portions of members **382**. Frame member **386** and frame members **384** are generally parallel to each other. These frame members are configured to provide slots **390** within which are received four sliding doors **392**. Each of the doors contain suitable opening mechanisms such as a row of teeth **1011** which provide a rack for a rack and pinion door opening mechanism **396** associated with each of the doors.

With reference to FIGS. **8** through **11**, the water cooling area **42** comprises a plurality of conventional heat exchangers **110**, five such heat exchangers being disposed along each side **651** and **653** of the support unit. Covering each one of the heat exchangers is a series of louvers **652** through which air enters from outside of the support unit and passes through the heat exchangers. On the other side of each heat exchanger is a series of deflecting vanes **118** which act to direct the air passing through the heat exchangers in the general direction as indicated by arrow **654**.

On top of the support unit in line with the heat exchangers are a series of longitudinally disposed fan assemblies **656**. Each fan assembly comprises one of the hydraulic motors **100**, and one of the fans **116**, as described hereinbefore.

Water from the eductor condensers **86** on the power unit travels through conduit **98** on the support unit in the direction indicated by the arrow **660** in FIG. **8**. This water is used to power the hydraulic motors **100** after which it is conveyed through conduit **662** to the heat exchanger **110** where the water is cooled. The water then travels through conduit **664** and into the water tank **52**. It should be pointed out that a conduit **662** and a conduit **664** is associated with each of the heat exchangers **110**.

The following is a description of the physical placement of the system components on the power unit. As shown in FIGS. **1** and **2**, the power unit includes an elongated frame **30** for supporting the structure of the power unit. Supporting the frame are four sets of drive wheels **34**, two sets of forward guide wheels in a 4-wheel truck **32**, and a rear set of guide wheels in a 2-wheel truck **31**. Secured to the frame is an elongated body or hood **610** defining a cavity for receiving the various elements of the power unit.

With reference to its orientation in FIG. **2**, the power unit cavity is filled in the following manner. At the extreme upper right hand corner outside of the cavity, there is provided cab module **11** which contains all of the elements necessary for the engineer to operate the locomotive. The back wall **612** of the cab rests up against a front wall **614** of the hood. The cab **11** is removably secured to the power unit by conventional fastening means, such as bolts (not shown). Positioned below the cab area within the cavity **612** on both sides of the frame centerline is a sand package **616** as well as batteries **618**.

Positioned behind the front wall **614** at the top portion of the cavity is the plenum **151**. The pair of exhaust fans **152** are placed within the plenum with their exhaust ports merging out of the top of the hood **610**. Positioned further behind the draft fans in the top portion of the cavity are the fintube economizer **128** and the superheater header **139**. Positioned next to the economizer along side hood side wall **622** is the feedwater heater **126**.

Below the plenum on either side of the frame centerline are the two high pressure cylinders **88**. These cylinders are positioned on the frame, one cylinder being positioned along each of the side walls **622** and **624**. Positioned below the exhaust ports for the fans in the lower portion of the cavity and behind the high pressure cylinders is the array of cyclone separators **326** below which is located the pan **330**.

Occupying a major portion of the cavity behind the feedwater heater is the furnace **20**. At the bottom of the furnace nearest the frame of the power unit is the shuffling grate **270** on which fuel is burned. Positioned forward of the general area defining the furnace is the pair of heaters **236** and **240**. Positioned above the air heaters, ahead of the furnace is the boiler section **24**.

Positioned behind the furnace, in the lower central portion of the cavity is the coal conveyor screw and stoker **130**. Above this structure is located the primary feedwater pump **66**, second water circulation pumps **96**, and the eductor condensers **86**. At the rear end of the power unit is the ash separator **143** and replaceable ash package.

Below the coal conveyor screw **130** near the rearward portion of the power unit are the two low pressure cylinders **166** located on opposite sides of the frame **30**.

With reference to FIGS. **1-13**, the locomotive **10** converts chemical energy in coal to work. The work is done by a tractive effort force acting through a distance. Chemical energy is released by combustion in the furnace chamber **132** resulting in hot flue gas containing combustion products and excess air. A portion of the chemical energy is transformed by radiative, convective, and conductive heat transfer into internal energy in water which is heated to the boiling point in the steam boiler **24** and to superheated steam conditions in the superheater **140**. The steam is conducted to the pistons **400** in the high pressure cylinders **88** and then to the pistons **402** in the low pressure cylinders **166** where its internal energy is converted into expansion work that is transmitted to driving wheels **34** and into tractive effort at the drawbar assembly **18** by a mechanical transmission consisting of piston rods, connecting rods, and cranks. The mechanical transmission and associated structure is discussed in detail hereinafter. Spent steam is condensed in eductor condensers **86**, cooled by forced convective heat transfer to ambient air, and stored in the water tank **52** on the support unit **14** until it reenters the boiler **24**.

The process is characterized by two major flows, air/gas and water/steam, whose paths interact resulting in transfer of thermal energy. The process is designed to maximize energy conversion efficiency of maximum recovery of available heat at every stage of the cycle. Some of the factors which improve thermodynamic efficiency are associated with how the flow paths interact; for example, use of exhaust flue gas for feedwater heating, use of extraction steam for air preheating, use of extraction steam for feedwater heating, and other uses which become evident hereinafter.

With regard to the air/gas flow path, furnace draft is provided by the induced draft (ID) fans **152**. Air enters the locomotive system through the inlet air damper **274** which is normally in a fully open position but can be closed in order to shut off the air supply for shut down or emergency conditions. The air passes through two stages of preheating by first passing through exhaust steam air heater **236** and then through receiver steam air heater **240**, each utilizing extraction steam from the low pressure cylinders **166** and high pressure cylinders **88**, respectively. The air divides into three separate paths whose individual flows are determined by inherent flow resistance factors. Approximately 35% of total air flow passes through a duct **282** into the wind box **272** under the furnace grate **270**. Approximately 65% of total air flow is delivered by duct **271**, which contains a series of spaced ports **145**, above the burning fuel bed **290** in such a manner as to create cyclonic motion of gases in the firebox **132** as indicated by the arrows **133** in FIG. **12**. Several percent of total air flow can also be injected at higher velocity by the air turbulator-blower **312** to augment the cyclonic motion.

Hot combustion gas passes through an opening **147** in the arch **320** to the upper furnace region **103**, transferring heat to boiler water through the furnace walls and arch tubes in the form of circulators **105** and enters the firetube section of the boiler **24**. As the gas passes through the firetubes **324**, it transfers thermal energy to boiler water surrounding the firetubes, and to steam in superheater tubes **140** inside the firetubes. Flue gas emerges from the firetubes into the flue gas plenum **151**, passes through the economizer where feedwater is preheated nearly to its boiling point, and then enters the array of cyclone separators **326** where fine solids and dust carried over from the furnace are collected. The pair of ID fans **152** draw their suction from multicyclone exhaust and spent combustion gases are discharged upward to the atmosphere as indicated by arrows **149**.

Water is stored in the storage tank **52** on the support unit **14**, and delivered by gravity to the suction booster injector **60** to provide positive suction head into the boiler feedwater pump **66**. The feedwater pump **66** is driven directly from the exhaust steam turbine shaft **176** via the speed reduction gear **178**; thus, pump speed is self-regulated in proportion to steam flow. A flow control valve **69** downstream of the pump **66** provides feedwater trim control. Boiler feed is pressure delivered to the feedwater heater **124** (heated by extraction steam from the high pressure cylinder **88**), then to the economizer **128** and to the boiler water space **135** as required to maintain the proper water level.

Steam from the boiler is collected in the dry tube **138** and delivered to inlet **144** of the superheater header **139**. Each superheater tube **140** has two loops in series, each loop in its own firetube. Steam is returned to the superheater outlet header **141**, then flows through the induced draft (ID) fan turbine **148** to the throttle valves **158** before entering the high pressure engine valve chest **161** of each of the two high pressure cylinders **88**. The Weiss port **182** supplies extraction steam through the non return valve **184** to the feedwater heater **124** and combustion air preheater **240**. Steam exhausting from the high pressure cylinders **88**, one of which is located on either side of the frame **30** near the forward area of the power unit, passes through the equalizing receiver **162** into the low pressure engine valve chest **201** of each low pressure cylinder. As best shown in FIGS. **3** and **21**, an equalizing receiver **162** is longitudinally disposed on either side of the power unit. Near the rear portion **600** of the power unit each receiver **162** is operatively connected to one of the low pressure cylinders **166**. A Weiss port **202**, in each low pressure cylinder **166**, supplies extraction steam through non return valve **222** for undergrate steam injection and combustion air preheating. Extraction steam condensate from both air preheaters **236** and **240** and feedwater heater **124** is returned to the water tank **52** through injectors **220** and **254**.

Steam exhausting from the low pressure cylinders **166** passes through the pair of low pressure exhaust turbines **172** on the common shaft **176** and into the pair of eductor condensers **86** where steam is condensed to water by intermingling with recycled tank water. The water jet into the condensers **86** is propelled by the first water circulation pump **80**, which is driven directly from the main power shaft **180**. Second water circulation pump **96**, which is driven from the exhaust turbine shaft, via speed reduction gear **178** and main shaft **180**, draws suction from the eductor condenser **86** and delivers high pressure water to the support unit **14** to power water turbines **100** and **38** for driving cooling fans **116** and the coal feed screw **130**, respectively. All water delivered by water circulation pump **96** is finally discharged into cooling coils **110** transferring heat from the water to ambient air, and then drains back into the water tank **52**.

With reference to FIGS. **2** and **12**, coal handling and distribution in the power unit **12** is handled in the following manner. Coal is conveyed from the support unit **12** by a standard stoker screw **130** with articulated joint connections **121** between the support unit and the power unit. Rotation of the screw **130** brings coal to the head of the stoker. Periodically, according to the firing rate required, the twin stoker rams **288** distribute coal forward over the coal bed. The rams are spring powered with steam return. They provide even coal distribution over the bed. The articulated slip joint **121** connecting power unit and support unit coal screws **130** and **130'** is accessible when the ash box **332** is removed. Where the coal screw **130** must bend, universal joints **127** are provided. Each of the universal joints in the coal screw is sealed or provided with oil lubrication.

As best seen in FIGS. **2** and **13**, the furnace **20** is a gas-producer type. Coal fed into the furnace chamber **132** is initially gasified in a thick fuel bed **290** supported by grate **270**. Primary air and steam are introduced into the windbox **272** below the grate. Gaseous products of this first combustion stage are burned in overbed region **300** in secondary overfire air. Hot combustion gases move in a cyclonic path **133** through the furnace arch **320** and through the back tube sheet **322** into the firetube convection pass. Heat is transferred by radiation from the fuel bed and flames, and by convection from hot gas to water-cooled surface for raising steam that encloses the furnace chamber.

Furnace volume (grate to tube plate) is approximately 380 cu. ft. A typical heat release rate at "notch-8" is 56×10^6 BTU/hr, corresponding to a firing rate of 4300 lb/hr for coal with heating value of 13,000 BTU/lb.

The furnace grate, shown in FIGS. **2** and **13**, is a "Detroit CC Grate" or equivalent, with lateral rows of grate bars **281**, each bar having a series of closely spaced pinholes **283**. Alternate grate bars move continuously in a slow, reciprocating or "shuffling" motion. The grate area is approximately 70 ft^2, and maximum coal loading is approximately 60 lb/ft^{2}hr. The fuel bed would normally reach a depth of one foot with newly injected coal on top, and shrunken coal particles and combustion residue below. The shuffling motion of the alternate grate bars **281** moves material deep in the fuel bed, consisting primarily of ash and clinkers, toward the rear of the furnace (that is, toward the point of fuel distribution) where it falls into a temporary ash pan **331**. Careful attention to prevention of leaks in the windbox container **272**, plus use of pinholes in the grate, assures uniform distribution of steam and air through the fuel bed.

An air-to-fuel ratio of approximately 13:1 is maintained to insure adequate air for combustion with some excess to avoid occurrence of corrosive, reducing conditions in the furnace.

The fuel bed temperature stays relatively cool because of partial combustion and steam injection. This method of combustion is inherently low in NO_x production because of low fuel bed and combustion temperature. It is also low in particulate emission because of low air and gas velocities passing up through the fuel bed.

Within the framework of the combustion within the furnace **20**, ash is a non-combustible component of coal that can account for up to approximately 15% of the weight of the coal. Ash consists of several constituents that vary in type and composition for different coals, and is a somewhat glassy material that becomes soft, sticky, and fluid as its temperature is increased. It remains after combustion in several possible forms depending on the type of combustion, and the temperature reached by the ash material in the combustion process.

In the furnace chamber **132**, fuel bed temperatures are low, and ash components are expected to stay in dry powder form and agglomerate into popcorn-size cinders and clinkers. Coal particles and lumps shrink as they are consumed in the fuel bed **290**. The ash material oozes out of the coal, flakes off, or agglomerates into medium size clinkers that gradually move to the bottom of the fuel bed and accumulate on the grate **270**.

With reference to FIGS. **2** and **13**, the furnace arch **320** is a refractory radiation shield supported by inverted "T" boiling water circulation tubes **105**, with a circular opening **147** for flue gas passage. The arch creates a furnace cavity trapping thermal radiation from the fuel bed to improve combustion and fuel bed temperature uniformity, and increasing heat transfer to water in the furnace walls for raising steam.

Below the arch, combustion gases move in a cyclonic pattern which continues through the arch opening into the upper furnace space **103** above the arch. This space is a convective heat transfer and transition region where gases enter the back tube sheet **322** and firetubes **324**.

With reference to FIGS. **13** and **14** water circulators **105** are provided in the fire box. Each circulator is in the form of an inverted "T", with three connections to the water space: one at the crown sheet and two to the side water walls. The circulators support the refractory arch **320** over the fire bed and provide natural water circulation around the fire box **132**. Even in low water conditions circulator action brings water from the side walls **670** to the top crown sheet **674**, flooding the crown **676**. The circulator nearest the firetubes has a small exit deflector which floods water forward over the highest part of the crown sheet to the backs of the flues.

The fire box is constructed steel conforming to ASME and FRA thickness requirements. It consists of a crown sheet **674**, two inner firebox side sheets **682**, a back sheet **686** with fire hole **688**, and the back tube sheet **322** which forms the front of the fire box **132**. The back tube sheet becomes a throat sheet below the forward end of the furnace arch **320**. The back sheet, crown sheet, and side sheets are supported by stay bolts **691** to the wrapper sheet **694** and **698** of the boiler. The wrapper sheet, which comprises the side water walls **694** and as well as the roof sheet **698**, and the fire box **132** are constructed in the Belpaire form which gives reduced thermal stresses compared to conventional fire boxes. Stay bolt spacing conforms to ASME and FRA rules for the required boiler pressure. The highest part of the crown sheet near the back tube sheet **322** is equipped with a fusible plug which will melt under low water conditions allowing water from the forward circulator **105** to flood the furnace space **132**.

The conventional mud ring of a locomotive furnace is replaced with a steel weldment **702** and refractory material **704**, as shown in FIGS. **13** and **14**. This design eliminates the need for a large casting for the mud ring. A manifold **706** in the ring **702** and is connected to wash-out connections **708**, shown in FIG. **6**, by suitable hoses or tubing (not shown) to clean ring **702** of any sediments or loose deposits.

Ash is transported by steam jet from the rear ash pan **331** up to the ash cyclone separator **143** and into the ash package **332**. The cyclone separator in the top of the ash package allows ash separation without release of fugitive dust into the atmosphere. The ash package is equipped for cleaning by means of washout plugs **800** on each side of the box or by bottom doors (not shown) which can be opened when the box is lifted from the locomotive.

Dry ash and ash agglomerates gradually move to the bottom of the fuel bed **290** as coal particles shrink and burn out, and accumulate on the grate. The shuffling motion of alternate grate bars **270** slowly moves bottom material in the fuel bed toward the rear of the furnace where it passes beneath a grate bar and falls into the rear ash pan **331** for temporary storage.

As stated before, the boiler design is a Belpaire construction with welded stay bolts **691** and seams. Welded stay bolts eliminate maintenance problems associated with threaded stay bolts and give adequate flexibility to absorb thermal expansions. The Belpaire configuration gives maximum steam space, simplified construction and configuration of stay bolts, and maximum resistance to thermal stress as compared to conventional locomotive boilers. The boiler is equipped with a top-located manhole **802** for access to the firetube region.

Boiler insulation **804** is provided by a 2-inch layer of fiberglass or other insulating material.

Furnace firetubes **324** are nominally 3.5-inch outside diameter, arranged in triangular array on 4-inch center-to-center spacing. There is approximately 1000 ft^2 of firetube surface area for heat transfer to boiler water for raising steam. Each firetube contains one loop of superheater tubing **140**.

The boiler is equipped with conventional railway-type safety valves **291** set according to FRA rules to relieve pressure above 300 psi. For clearance, the safety valves are mounted on each side of the boiler roof sheet **698** with a self draining tube **806** extending into the steam space over the crown sheet. Four safety valves **291** are included for redundancy.

The blackhead **808** of the boiler is equipped with standard pressure gauge, water level gauge glass and water gauge cocks. These instruments can be checked by inspection from the auxiliary compartment **544** and compared to remote readings in the locomotive cab **11**.
p Make-up water and boiler water are treated in accordance with customary boiler practice. The effect of the

water treatment and the condensing steam cycle is to radically reduce boiler maintenance compared to known locomotive practices. Corrosion and sedimentation are minimal and scale no longer forms. The combination of all-welded construction and treated boiler water results in a minimum of maintenance required at firetube ends, circulator ends, stay bolts, and mud ring area.

A small amount of blowdown is provided from the mud ring region, which is conveyed back to water storage or blown to the field. Design blowdown is approximately 333 lb./hr. The blowdown prevents sediment accumulation in the mud ring.

The flue gas plenum **151** includes a mixing space **812** where flue gas flow recombines after having passed through the multiplicity of firetubes. It also includes space for the economizer **128**, feedwater heater **124**, multicyclone inlet **814**, and ID fans **152**. The mixing space also contains the superheater inlet and outlet headers **144** and **141**, and all superheater tubes **140** that enter and return from the firetubes.

The economizer **128** is a compact, modular heat exchanger, externally finned to increase effective area on the flue gas side. It heats feedwater close to saturation temperature before it enters the boiler. The economizer can be removed as a single assembly for maintenance and repair, and for access to superheater assemblies and multicyclone dust collectors **326**.

A drum-like enclosed feedwater heater **124** is in the plenum chamber **151**. Feedwater circulation through the feedwater heater comes from the primary feedwater pump **66** with discharge to a water inlet check valve at the side of the boiler. The feedwater is heated by steam extracted from Weiss port **180** in high pressure steam cylinder **88**. Condensed steam is conveyed back to the water tank **52** in the support unit **14**.

Flue gas leaving the economizer passes through a battery of cyclonic dust collectors **326** for gas clean-up.

Cyclone collection efficiency is a function of gas flow rate through the cyclone **326**. A battery of multicyclone collectors is employed such that at lower gas flow rates, the number of cyclone collectors in the gas stream can be reduced to insure that individual collectors are always operating with high efficiency regardless of total gas flow and locomotive power level.

Individual cyclones in the multicyclone battery discharge solids into the collection hopper or separator **328**. Hopper volume is large enough so that clean-out will never be required more frequently than fuel pack replacement, and for most coals, will be required less frequently. Clean-out may be accomplished by any well known method, such as gravity drain, vacuum flush, or water washout; or the fly ash can be conveyed by air or steam jets through a tube to the ash box **332**.

The furnace draft is provided by the induced draft (ID) fan **152**. In a preferred embodiment, the ID fan consists of two identical squirrel-cage blowers **152** mounted on a common shaft **150** and driven by a single-stage steam turbine **148** in the main steam line between superheater outlet header **141** and main steam throttle **158**. ID fan speed is nominally self-regulated in proportion to main steam flow rate. A steam bypass (not shown) may be provided to accomplish trim control on ID fan speed and furnace draft. Fan exhaust is directed vertically to the atmosphere as indicated by line **149**.

Saturated steam from the water/steam space **135** at the top of the boiler flows through four steam inlet pipes **820** into the large central dry pipe **138** that conveys the steam to the superheater header **139** mounted at the front tube sheet **157**. The steam passes through the double pass superheater **140**, to the ID fan turbine **152**, via conduit **156** to the pair of Wagoner throttles **158** on top of the valve chests of each high pressure cylinder **88** for accurate control of steam flow at the last instant before steam passes through the high pressure piston valves **163**. Main steam passes through the piston valves and into the high pressure cylinders **88** where it acts on the pistons **400**.

Steam exhausted from the high pressure cylinder **88** passes from the ends of the high pressure valve chest **161** to the receiver pipe **162**. There is one receiver on each side of the power unit **12** joining each high pressure cylinder **88** with one of the low pressure cylinders **166**. Crossovers **822** join the receivers and cylinder chests on both sides of the power unit.

An oil separator **824** is provided in each receiver **162** to remove any small quantities of lubricating oil before the steam passes to the low pressure cylinder valve chest. Oil removed by the separator is injected into the fire bed so that no servicing of the oil separator is required.

With reference to FIG. **22**, each high pressure cylinder valve chest **161** contains a piston valve **163**, 15 inches in diameter with 9-inch maximum travel. All steam ports are of maximum available flow area to insure the lowest resistance to high volume steam flow. The valve chest **161** has inside admission with exhaust ports **160** and with Weiss ports **182** at each end to equalize pressure at the ends of valve stroke. The valve is designed to be of light weight. In each valve a tubular hollow spindle **830** is driven by a suspended linkage **833**. Within the spindle is mounted drive rod **835** by pivot pin **837**. A damper **850** at one end eliminates longitudinal vibrations. The valve rings **858**, **860'** and the packing **859** are of the same type as used in the low pressure cylinder for optimal lubrication control, and the valve moves inside a removable liner **600**, similar to the liner in the low pressure cylinder **166**. The valve and valve chest are designed for ease of disassembly for maintenance.

With reference to FIGS. **21-25**, receiver steam feeds each low pressure cylinder valve chest **201** via inlet ports **164**. Because of the large steam volume, each chest contains two outside admission valves **165** which are driven as a pair. Each valve is 15 inches in diameter with a 9 inch maximum travel, and similar in construction to the high pressure cylinder valves **160**. In each valve, a tubular hollow spindle **820** is driven by a suspended linkage **832** within the spindle is mounted drive rod **834** by pivot pin **836**. The drive rod **834** can be displaced from longitudinal alignment with the valve spindle. (This same spindle and rod arrangement may also be applied to the high pressure cylinder valve.)

Located below the valve chest **201** is of the low pressure cylinder **166**. The low pressure cylinder has a generally hollow cylindrical configuration within which the piston **402** and its integral piston rod **846** travel. The piston rod **846** is disposed for longitudinal movement within the cylinder portion. The piston rod emerges from both ends **850** and **852** of one cylinder portion. At the end **852** there is located an extension cap **854** which receives the piston rod on its return stroke, because the piston rod is of the extended type.

At each of the cylinder ends **850** and **852** there are a series of conventional packing rings **860** along with conventional packing material **861**. A similar packing arrangement is provided for the valve rod **834** and is generally designated as **860'** at each end of the valve chest as shown in FIG. **23**. At one end of the valve chest there is provided a fluid dampening piston **862** which is secured to the spindle tube **828** by a pivot pin **864**. The packing arrangement, for both the valve chest and the cylinder portion, through the use of a plurality of packing rings, provides a superior seal against steam leakage.

The interior **842** of the cylinder portion contains a cylindrical liner **601**, made of a material known for its resistance to frictional wear, such as high grade steel. In turn, the peripheral portion **603** of the piston **402** contains a series of rings **605** made of a softer material to provide superior gliding of the piston along the liner **601**.

Lubrication is radically different than in standard steam practice. Lubricant is delivered to the rings, cylinder and valve chest walls as in diesel engine practice.

As noted before, the mechanical descriptions of the high and low pressure cylinders are similar except that the low pressure piston is larger in diameter. The low pressure piston carries a clearance skirt **611** so that piston clearance volume is minimized yet a large port opening can be provided.

The low pressure cylinder is surrounded with a steam jacket **613**, as indicated in FIG. **23**, which reduces heat loss and provides thermal insulation.

The combination of two-stage compound expansion, insulation around all steam passages, piping, valve chest, the cylinders and steam jacketing reduces thermal losses in the steam power cycle.

Another oil seperator **401** is provided in the steam passages from the low pressure valve chest exhaust to the exhaust steam turbines to remove oil and lubricant before steam is passed to the eductor condensers and water coolers.

Steam exhausting from low pressure cylinders **166** is most advantageously at less than atmospheric pressure (partial vacuum) which improves engine efficiency through reduced back pressure. The partial vacuum is maintained by a combination of steam condensation and pump suction, which will be discussed in greater detail hereinafter. The better the vacuum, the more work that is potentially available in the expansion cycle. However, at very low back pressures, the specific volume of steam is quite large which requires large exhaust steam pipe dimensions. This is a serious practical limitation. Thus, there is additional expansion energy in the steam, equivalent to several hundred horsepower, which is not available in the steam engine expansion cycle, but could be harnessed by other means.

In a preferred embodiment, low pressure cylinder exhaust pressure is approximately 7 psi (about one-half an atmosphere, absolute) which is the practical lower limit to cylinder exhaust pressure. Exhaust steam is then expanded further, immediately upon leaving the cylinder **166**, to a pressure of approximately 3 psi in the exhaust steam turbine **172** which, in turn, exhausts directly into the eductor condenser **86** to reduce its specific volume and eliminate the need for large steam pipe diameters to conduct low pressure steam to condensing coils **110**. Thus, the low pressure cylinders **166** are operated in the most practical and efficient manner, and useful energy is also extracted from exhaust steam which would otherwise be lost. The energy from the exhaust steam turbine **172** is used to drive the balance-of plant equipment (water circulation pumps **80** and **96**, and the main boiler feedpump **66** roots air turbulator/-blower **312** and primary generator **532**.

There are two exhaust steam turbines **172**, one at each low pressure cylinder exhaust **168**, arranged to drive a common, lateral shaft **176** for power take-off. Turbine exhaust steam is directly entrained by a pair of eductor condensers **86** which share a common steam enclosure with each exhaust steam turbine.

Exhaust steam from each exhaust steam turbine is desirably close to saturation at a partial pressure of approximately 3 psia. To maintain such conditions requires condensation, vacuum pumping, or a combination of both. The eductor condenser **86**, whose performance is well-known, performs both functions. Steam is condensed by mixing with sub-cooled water taken from the water tank **52** of the support unit **14**. The mixing occurs by eductor action, whereby the steam is entrained in a forceful jet of sub-cooled circulating water whose high velocity serves to maintain the vacuum back pressure on the steam. The required mass flow of circulating water is approximately 40 times greater than the mass flow of entrained steam to adequately condense the steam. Even though the circulating flow rate of water from the support unit to the condenser **110** and return is so much greater than net steam flow, the great reduction in specific volume of the fluid makes the process an advantageous alternative for the condensing cycle.

In the event of failure of any one of the exhaust steam turbine **172**, condenser **86**, support unit cooler **42**, or in the case of extremely hot and unusual environmental conditions (air temperature greater than 110° F.), such that partial vacuum back pressure can no longer be maintained, an emergency free exhaust port **403** leading upward to the atmosphere from the condenser enclosure can be opened permitting non-condensed steam to escape from the eductor condensers **86**. This could enable continuous locomotive operation, possible at severely derated horsepower depending on extent of locomotive system failures, until water storage is depleted.

With reference to FIGS. **2** and **4**, water circulation pump **96** is a gear pump, although other pump types are contemplated. The pump draws suction from the exhaust of condenser **86**, and helps maintain vacuum back pressure at the exhaust steam turbine outlet **171** and low pressure cylinder exhaust port **168**.

It is driven by direct coupling to the exhaust steam turbine shaft **176** via speed reduction gear **178**, and its pumping rate is nominally self-regulating in proportion to steam flow. At full locomotive power, mass flow rate of circulating water is approximately 1.3×10^6 lb/hr.

The pump **96** delivers high pressure water to the support unit **14** which drives cooling fans **116** and the coal stoker motor **104** with water turbines. The circulating water then passes through cooling tubes **110** and returns to water storage tank **52**.

With reference to FIGS. **31–33**, the interconnections between the power unit **12** and the support unit **14** are shown. With regard to FIG. **33**, the right-side end of the support unit is shown with the various interconnections.

As oriented in FIG. **33**, in the lower left hand corner of the support unit there are two flexible hoses **502** and **504**. Hose **502** is connected by a quick disconnect with a similar hose **502'** on the power unit and conveys water from the water tank in the support unit to the feedwater pump **66** via the suction booster injector **60** both of which are contained on the power unit. Hose **504** is interconnected by a quick disconnect with a similar hose **504'** on the power unit and provides an auxiliary connection to conduct water from the water tank **52** on the support unit to an auxiliary feed water pump **540** should one be employed in the system.

Located above hoses **502** and **504** in the lower left hand portion of the wall of the support unit, is an 8 inch flexible hose **506** which mates, by flange connection, with a similar hose **506'** on the power unit and acts to convey water from the eductor condenser **86** located on the power unit to the water tank located on the support unit.

Located at the lower right hand portion of the wall of the support unit is another 8 inch hose **508** which mates, by flange connection, with a complimentary hose **508'** on the support unit and conveys water from the water tank **52** on the support unit to the eductor **86** on the power unit.

Centrally located in the lower portion of the wall of the support unit is the stoker screw **130** which through a suitable coupling **121** is connected to a complimentary structure **130'** on the power unit. Below the stoker screw is the draw bar **18** and safety bar slot **16**. Located below this structure is the buffer **411**.

Located to the left of the draw bar and slightly below the stoker screw are series of hoses generally designated as **510**. One of these hoses **512**, by flange connection, mates with a similar hose **512'** on the power unit to provide steam from the power unit to an auxiliary stoker engine, should one be employed in the support unit. A second hose **514** by Cannon plug connection or equivalent mates with a similar hose **514'** in the power unit and contains all wiring to provide an electrical interconnection should the locomotive system **10** be employed in a multiple unit operation. The remaining four hoses **516** with glad hand connectors are air hoses used in a multiple unit interconnection.

To the right of the draw bar slightly below the stoker screw is a set of hoses generally designated as **520**. One of these hoses **522** by quick disconnect is interconnected with a similar hose **522'** on the support unit to provide steam from the low pressure cylinders **166** to the coal draw on the support unit in the form of coal wetting steam **228**. A second hose **524** by glad hand connection provides yet another interconnection with the power unit for operation of the air brakes on the support unit. The remaining four hoses **526** with glad hand connections are air hoses which are used for multiple unit operation in a manner similar to hoses **516**.

Flexible pipe connections eliminate right angle ball joint connections which would interfere with high volume recirculating water flow rates.

With reference to FIG. **35**, the locomotive **10** has a four cylinder **88, 166** opposed piston engine. Each pair of pistons **400, 402** on each side of the power unit **12** are in dynamic opposition, **180** degrees out of phase.

Inside coupling rods **481**, arranged on crank axles **483**, keep the pistons in dynamic opposition. They normally transmit only the difference in thrust between the high pressure pistons **400** and the low pressure pistons **402**, except during wheel slip. Therefore, average loading in service on these coupling rods will be small, but they must be designed, nonetheless, to absorb temporary high thrusts when a portion of the drive unit loses adhesion.

Crank axles **483** for the coupling rods are set at 90 degrees. This insures even distribution of force through the coupling rods and axles under all conditions.

The crank axles **483** can be built up as shown in FIGS. **26** and **27**, or can be one piece forgings. If built up using a shaft **485** and a web **487** as shown, crank counter weights **489** can be provided in the crank axle web **487**. But the crank axle must be disassembled to replace coupling rod bearings **491**. If crank axles are one piece forgings, however, then better accessibility can be provided to coupling rod bearings, but any coupling rod counter weights must be placed in the main drive wheels.

In a conventional steam locomotive, counterweights on drive wheels must balance not only the revolving weights attached to the drive wheels, but also the effects of reciprocating mass. Additional counter balance mass is placed in wheel counterweights to give some dynamic opposition to longitudinal and oscillating piston thrusts. This so called excess mass causes drive wheels to be out-of-balance in rotation. At high RPM, the inbalance condition can severely damage rails due to excessive oscillating vertical pressure. If excess mass is reduced, unbalanced reciprocating piston forces will cause the locomotive to oscillate laterally and also damage the track. Conventional balancing practice was, at best, a compromise.

With regard to a preferred embodiment of the driving gear layout shown in FIG. **35**, the opposed piston pairs **400, 402** on each side of the locomotive result in nearly perfect reciprocating balance. The smaller high pressure piston **400** can be provided with additional weight to equal the weight of the low pressure piston **402**, if necessary. With such an arrangement, driving wheel counterweights **981** serve only to balance revolving masses attached to the wheels. Side rods **493** connected to drive wheels can be perfectly balanced using conventional cross balance techniques. Main connecting rods **495** can be balanced by the center of percussion technique to find the equivalent revolving mass.

In the locomotive, according to the teachings of the present invention, it is practical to achieve near-perfect rotary balance in all planes of each drive wheel pair. The total effect on the rail of unsprung weight and the rotary characteristics of each drive wheel is similar to a passenger car, and more favorable than a standard diesel locomotive driving axle with assymmetrically suspended traction motor.

The key advantages of the balanced drive system are as follows:

(1) The four cylinder layout allows for easy application of compound steam expansion.

(2) All cylinders, crossheads **497** and main connecting rods are easily accessible for service and maintenance. Pistons and associated running gear machinery can be easily removed without full disassembly of the entire running gear system.

(3) All bearings in the running gear system are either spherical roller bearings or tapered roller bearings. Locomotive speed is limited only by the centrifugal forces which these roller bearings can take. This drive gear system can run at much higher speeds than conventional steam locomotive running gears.

(4) Piston thrust is divided among four cylinders instead of two. Stress on crossheads, pins (such as main pin **983**), rods and so forth are reduced by two, compared to an equivalent 2 cylinder engine.

(5) Because of the inherent balance and higher dynamic speed capability, the drive system can use smaller drive wheels than would normally be ac-

ceptable. Smaller drive wheels permit better pulling characteristics at low speed, while the balance characteristics allow the drive to run at the highest permissible track speeds without stressing running gear or track excessively.

(6) Inside coupling rods insure synchronization. These rods need absorb only the difference between piston thrust at each end of the engine. Therefore, the coupling rod bearings **491** can be over-designed and sealed, requiring maintenance only when main drive wheel axle bearings are maintained.

(7) The first axle **561** and fourth axles **563** in the driving gear are equipped with conventional lateral motion restoring and cushioning devices **565**. This shortens the effective rigid wheel base to approximately 6'-6", that is the distance between the second and third driving axle centerlines. This short rigid wheel base combined with lateral motion of the first and last driving wheels provides for a driving gear which can easily negotiate sharp curves and remain laterally stable at high speeds.

All axles and rods equipped with roller bearings. Adequate lubricant space is provided in all bearings to give an extended time between servicing. Tapered roller bearings are applied to all axles **569**; spherical roller bearings **567** are applied to all side rods, connecting rods and coupling rods.

With reference to FIG. **2**, the spring rigging system **571** follows conventional practice, using overhung equalizers **573** with underhung springs **575** in a continuous spring and equalization system running from the front to the back of the locomotive. Each end of each spring system tying the springs of several wheels together are equipped with coil spings **577** so that the connection between spring systems and frame is not entirely rigid. Spring and damping characteristics should be carefully chosen to insure longitudinal and lateral locomotive stability at all operating speeds.

Locomotive equalization and spring rigging follow the standard "tripod theory". The front leg of the tripod consists of the four wheel engine truck **32** riding on its lateral bolster **581**. Each of the other two tripod legs consist of four driving wheels **34** and one wheel of the trailing radial truck **31** equalized together down each side of the locomotive. The equalization system continues through all four driving wheels on a side and connects to a wheel of the radial truck on the same side. FIG. **2** shows the equalization connection between driving wheels and radial truck. No cross equalization is provided; each side forms an independent equalized suspension system. With the locomotive's suspension resolvable into a single tripod, wheel loadings on each drive wheel remain constant despite vertical pitching or oscillation of the locomotive. The constant wheel loading insures good adhesion and traction under all conditions.

The engine leading truck **32** is designed with conventional, lateral moving, self-centering geometry which will be provided with either gravity or spring centering with increasing or constant resistance under lateral deflection. The design of the four wheel truck and its incorporation into the running gear layout follows conventional practice which insures full stability and low flange loadings for the locomotive when running on straight track or entering curves at various speeds.

The radial truck **31** is equipped with a centering device **583** with only slightly increasing or constant lateral resistance. When the locomotive is running with the support unit forward, the radial truck provides horizontal guidance to the locomotive and eases flange loadings when entering curves. Lateral resistance is designed to complement lateral resistance of the four wheel engine truck.

Brake rigging follows conventional practice with two shoes **591** per wheel on most wheels in both power unit **12** and support unit **14**. The driving wheel brake system is shown most clearly in FIG. **6** and consists on each side of three pairs of brake shoes. Each pair of brake shoes is opposed and equalized by a lever arrangement **593**. This arrangement provides two shoes per wheel on the second and third driving axles. The lever arrangement consists of two vertical links **595**, each fixed at one end to the frame by pivot **597**. The other ends pivotally receive cross-link **599**. A brake shoe **591** is secured to each vertical link. The air brake cylinder immediately under the air heaters provides brake action for three pairs of driving wheels and an air brake cylinder mounted over the radial truck provides the brake action for the pair of driving wheels under the fire box.

With reference to FIGS. **19** and **20**, the frame is a standard bar type with transverse pedestal ties **951** to close the frame underneath the driving wheel axles. This frame is constructed entirely as a weldment with incorporation of cast steel in key parts such as coupler pockets, frame ties, and cylinder supports. Jacking beams **953** are incorporated at each end of the frame to allow easy jacking of the entire locomotive to service or remove running gear parts. Jacking beams eliminate the need for a large overhead shop crane, and to allow the locomotive to receive heavy service in existing diesel locomotive shops.

The drawbar **18** and safety bar **16** between the power unit **12** and support unit **14** are shown in FIGS. **2** and **6**. The drawbar is made as long as possible to improve vehicle dynamics when running with the support unit forward. With the long drawbar and wide radius buffers **411**, pushing action from the power unit to the support unit occurs on a centerline which is as close as possible to the track centerline in curves to minimize lateral pushout.

As shown in FIG. **34**, each of the buffers **411** contains a radial buffer face **413** in the form of a gently curved face generally normal to the plane defined by a pair of railroad tracks **415**. The radial buffers between the power unit and the support unit complement the drawbar. The radial buffer design prevents longitudinal slack, and provides favorable pushing characteristics at all operating speeds.

The exhaust steam turbine **172** drives the reduction gear **178** as shown in FIG. **4**, and this reduction gear drives the main power shaft **180**. Because the turbine speed is nominally self-regulated in proportion to steam flow, power delivered to machinery coupled to the power shaft is nominally proportional to locomotive power output. The power shaft **180** is divided into two sections **417**, **419** with universal coupling **421**, and is supported by three conventional roller bearings **423**.

As shown in FIG. **4**, the feedwater pump **66** is mounted on the right side of the power shaft **180**. It draws water from the storage tank **52** in the support unit and delivers it first to the feedwater heater **124** and then to the economizer **128** mounted ahead of the front tube sheet **157**. The pump **66** is centrifugal with sufficient capacity to provide 150 percent of nominal water flow required at full power.

Water circulation pump **80** is mounted on the left side of the power shaft **180** and delivers water from the water tank **52** on the support unit to the twin eductor condensers **86**. Nominal pump capacity is 2600 gpm at relatively low head.

Two V-belt groups **530** are used to drive the primary generator **532** and Roots air turbulator/blower **312** from the power shaft **180**. The primary generator has windings to supply AC and DC power for all locomotive electric power requirements. The Roots turbulator/blower **312** provides high pressure air for injection into the furnace combustion chamber **132** to improve cyclonic circulation. Excess high pressure air is fed to the main air brake reservoir. The Roots air blower is equipped with a suitable filter **1021** to prevent the ingestion of dust.

Number two water circulation pump **96** consists of two gear pumps driven by the power shaft **180**. Each gear pump draws suction from the eductor condenser **86** immediately above.

The auxiliary feedwater pump **540** provides water to the boiler when the primary feedwater pump **66** is not turning or is delivering less than the required volume flow. This pump is mounted on the left side of the boiler immediately in front of the air heaters **236, 240**. It is a steam driven pump with two stages of steam expansion compounded and a single water stage, with all three pistons mounted on a common shaft. The auxiliary feed pump draws water from the support unit storage tank **52** for delivery to the feedwater heater **124** and economizer **128**. Exhaust steam from the auxiliary feedwater pump passes through a small oil separator and then exhausts to the eductor condenser chamber or directly to the water storage tank **52**.

Two standard Westinghouse-type compound air brake compressors **542** are mounted in the auxiliary compartment **544** on the backhead of the boiler. They pressurize the primary air brake reservoir. Stam exhaust from the air compressors passes through an oil separator (not shown) and is fed to each eductor condenser **86**, or directly to the water storage tank **52**.

An auxiliary steam driven generator **546** mounted at the back of the auxiliary compartment **544** provides electric power when the primary generator **532** is not turning. The auxiliary generator has windings to provide AC and DC power sufficient to provide for all electric requirements of the locomotive while standing, idling, or during startup of the furnace. The auxiliary generator exhaust passes through an oil separator to tank **52**.

Standard sanding apparatus **633** (employing standard pneumatics, not shown) is provided to locomotive driving wheels as shown in FIG. **6**. In addition, pre-sanding nozzles **635** are provided on engine and trailing trucks. When running with the power unit forward, the pre-sanding nozzle under the power unit cab **11** is activated; with the support unit forward, the pre-sanding nozzles at the radial truck are activated. Each puts a small amount of sand on the idle wheel that precedes the driving wheels. This increases effectiveness of sand to the drive wheels.

Battery compartments **618** are provided under each corner of the cabs of both the power unit and support unit. These four battery compartments on the locomotive provide heated space for battery storage including space for excess battery capacity. The batteries are readily accessible from the ground.

With reference to FIG. **12**, the manner in which many of the system elements are controlled will be described.

The ID fan **152** is turned by the steam turbine **148** mounted on the same shaft **150**. The steam is main steam, and the turbine is immediately down stream from the superheater outlet header **141**. The system is inherently self-regulating. A turbine bypass valve **560** provides trim control in ID fan speed. Control of the turbine bypass valve **560** is based on deviation of flue gas flow rate from set point valve determined as a function of steam flow. Flue gas flow rate is determined by measuring pressure drop across the firetubes.

The self-regulating feature provides feedforward control action. Feedback control trims the turbine bypass valve on the basis of flue gas flow rate error (deviation from load dependent set point). Anticipatory control is provided by steam pressure error. For example, a sudden increase in steam flow (open throttle or longer cut-off) will cause a steam pressure drop. Quick response by the ID fan to increase draft will minimize the steam pressure drop.

The stoker motor **38** is powered by circulating cooler water whose flow rate is directly coupled to low pressure cylinder exhaust steam flow by the exhaust steam turbine **172**. Stoker motor control in inherently self-regulating. Trim control is provided by a series throttling valve based on a function of main steam flow. Since coal feed is a relatively slow process, there is no need to respond to short term deviation of steam pressure from set point—only longer term changes.

The main boiler feed pump **66** is driven from the exhaust steam turbine **172**. Feed pump control is inherently self-regulating. Trim control of the feedwater flow control valve may be based on a conventional 2-element level control sensing water level and steam flow.

Several control philosophies are possible for throttle and cut-off. In a preferred embodiment, the one selected initially is analogous to diesel locomotive control in that the engineer will manipulate a "locomotive throttle" with off, idle, and eight notch positions, where each notch corresponds to a target value of indicated locomotive horsepower. Control action is initiated by deviation of actual indicated horsepower from the targeted value, and this action results in manipulation of throttle valves and advancing cut-off to the high pressure and low pressure cylinders **88** and **166**.

Cab controls are shown in FIGS. **3** and **4**. The throttle lever **701** is a conventional diesel type throttle lever with 8 notch positions. This same throttle lever can provide a parallel signal to diesel locomotives in tandem to set the diesel throttles in the same notch position as the steam locomotive throttle lever. The reverse control handle **703** in the cab simply provides for forward, neutral and reverse direction of operation. A dynamic brake handle **705** is also provided at the operator control position with 8 notch positions, like a conventional dynamic brake. The dynamic brake handle in the cab can also provide a parallel signal to the dynamic brakes of diesel locomotives in tandem to set their dynamic brakes at a similar position.

In essence, under the principal of dynamic braking, the cylinders provide a retarding action against negative work while the locomotive and the train are proceeding downhill. The pistons work against the small amount of steam and the valve gear is set in a moderately reversed position.

Adhesion control can be divided conceptually into two functions. One is the prevention of slip in real time and the second is the maximumization of available adhesion by generating a controlled amount of slip in the drive wheels to maximize traction. Both functions of adhesion control are facilitated by locating the Wagoner type throttle **158** as close to the high pressure valve chest **161** as possible to reduce storage and transit delay times. Then the adjustment of cut-off and valve timing in the shortest possible reaction time is essential. Therefore, moving parts involved in changing valve cut-off and timing should be designed for minimum inertia. Positive control of the cylinder cocks (FIGS. **22B** and **23B**) can also prevent slips by venting excess cylinder pressure immediately if required.

As best illustrated in FIG. **6**, the valve gear, generally shown as **461**, is a standard Walschaert locomotive valve gear, equipped with needle and roller bearings throughout. Two options of valve gear cut-off controls may be provided. The first option (FIG. **24**) uses a linkage **463** from a mechanically or electrically controlled servo **465** and air cylinder **467** to change valve cut-off timing. The second option (FIG. **25**) uses electronic servo control **469** on the air cylinders **473** to control pistons **471** which change valve cut-off. This option minimizes physical mass and number of moving parts involved in changing valve cut-off position, and allows cut-off adjustments in the minimum possible time.

In both FIGS. **24** and **25**, the valve gear basically comprises a low pressure cylinder valve rod **834** and a high pressure cylinder valve rod **835** each being pivotally connected to one end of a combination lever **351**. The other end of the combination lever is pivotally connected to a union link **353**, one end of which is movably secured to a crosshead **355**. Pivotally connected to the combination lever is a radius rod **357**, the free end of which is pivotally connected to a bell crank **359**, in the case of the low pressure cylinder. Each of the main rods is pivotally connected to one end of an eccentric crank **361** which, in turn, is pivotally connected to an eccentric rod **363**.

The end of each eccentric rod is pivotally connected to a link **365**; in one case, the bell crank **359** rides in a space provided over the link **365**. In the case of the radius rod associated with the high pressure cylinder, the end of that radius rod rides in the link **365**. Also provided is an arcuate track or path **1001** within which the end **1002** of the combination lever **351** moves to provide a pendulum suspension.

In the embodiment shown in FIG. **24**, one end of a reach rod **367** is pivotally connected to the free end of bell crank **359** and is pivotally mounted to one end of a second reach rod **369** by pivot **371** which rides in a fixed curved channel **373**. The other end of reach rod **369** is pivotally connected to a third reach rod **375** at pivot point **377** to which is further connected yet another reach rod **379** that has its end connected to a stationary pivot point **381**.

The free end of reach rod **375** is connected to one end of a bell crank **383** which has its other end connected to radius rod **357** on the high pressure side via reach rod **385**. At pivot point **377**, there is connected yet another reach rod **387** which is pivotally connected to the piston **465** of cylinder **46C**.

The object of the reach rods and reach rod control cylinder is to make a vertical adjustment on the back end height of the radius rod. This height determines the length of the stroke of the valve. For a full stroke of the valve, which is referred to as full stroke, the radius rod has to be lifted to the extreme top or extreme bottom position in the link. Whether the rear end of the radius rod is lifted to the top or the bottom of the slide in the link, determines whether the engine proceeds forward or backward. If the end of the radius rod is further down in the link, the power unit would go in a forward direction, and if the rear end is all the way down in the link, then the power unit goes in a forward direction with the valve running at full cut-off for full stroke.

If the end of the radius rod goes down only a small amount from the center, then the power unit would still be going in the forward direction but the valve would only be moving a short travel or stroke, with a short cut-off. In symmetrical fashion, if the radius rod is lifted all the way to the top of the link, then the engine would proceed in reverse direction, but with full valve stroke, and then if the radius end of the rod were lifted up a slight amount, then the engine would go in reverse direction, but the valve would be moving with a short stroke.

Valve stroke setting is a key factor in controlling engine power. At a full valve stroke, steam is admitted to the cylinder during the entire piston stroke. At partial valve stroke, steam is admitted to the cylinder only during a portion of the piston stroke up to the so called "cut-off" point.

At full valve stroke the steam exerts maximum thrust against the piston for almost the entire piston stroke. However, the steam remaining in the cylinder after the stroke still contains energy that could have been utilized for expansion work, but is lost as the cylinder is exhausted in preparation for the next power stroke. At partial valve stroke more of the steam energy is utilized for expansion work, but the piston thrust decreases during the piston stroke.

An objective of locomotive control is to convert energy in the steam to draw bar horsepower most efficiently which often requires the shortest possible valve stroke to maximize steam expansion in the cylinders consistent with train speed and tractive effort requirements.

FIG. **24** is a mechanical way to achieve the required vertical adjustment in the back end of the radius rod. In a conventional system of adjusting rods and reach rods, all of the rods are usually static and only the radius rod, link eccentric rod, eccentric crank, and other rods connected to the crosshead are actually going to be moving back and forth in rhythm with the driving wheels. In the system of FIG. **24**, the reach rods are set at some adjustment and, then, if power is needed from the engine, a control signal from the engineer would add some air pressure to the control cylinder which would then move the bell cranks to move the end of the radius rod to a different place in the link.

FIG. **25** illustrates another way of regulating the control cylinders, which change the position of the back end of the radius rod. It can be seen in the drawing that the amount of mechanical linkage has been reduced to an absolute minimum. Rather than having a mechanical linkage to make adjustment in the height of the back end of the radius rods, in FIG. **25**, it is done with an air cylinder connected directly to the end of the radius rod. The adjustment cylinders are controlled by the servos which are connected directly to an electronic control in the cab.

By having all the reach rods and bell cranks eliminated, inertia is reduced to a minimum, and response time to effect a valve timing adjustment is reduced.

The locomotive is adaptable to either a standard air brake system as is currently produced in this country or could incorporate an electro pneumatic electronically controlled system. In the drawings, a standard Westinghouse #26-L brake system is incorporated in the locomotive because this is the most advanced brake system currently in use on American railroads. However, electronically controlled braking would be easily adaptable to the locomotive.

One air reservoir **961** is provided on the power unit on top of the boiler on the left side as shown in dotted lines on FIG. **2b**. Two air reservoirs **963** are provided under the frame of the support unit, shown in FIG. **8**. All three reservoirs are fed by the air brake compressors and the tanks are equipped with suitable drains which may be opened from ground level by a member of the crew.

Two seats **261** are provided in the cab to accommodate two locomotive crew members as currently required in most railway union agreements. However, the locomotive is designed to be operated entirely by the locomotive operator in the right hand seat. The person riding in the left hand seat serves simply as safety observer or the seat may be occupied by a conductor of the train and a suitable desk light is provided for this use. In addition to the two main seats, two additional folding jump seats **263** are provided on the back wall behind the doorways.

The cab design incorporates current safety features for crew protection in collisions with other trains or collisions with vehicles at grade crossings. Because the cab is short in length form front to back, the nose portion **501** is built of extremely strong structural members to absorb impact crash loadings. The collision shield **503** is a solid reinforced panel with no doors or hatch penetrating through it. The collision shield is angled in top plane view and the side view is angled in a slightly forward position to deflect objects which may be struck by the locomotive and prevent these objects from riding over and penetrating the cab. The lack of doors or hatches in the collision shield is designed to prevent flaming liquid or gasses from penetrating the cab during any serious crash. The windshield panel **505** is sloped backwards for deflection and also angled in planeview. Three intermediate posts **507** are provided in the windshield panel to help prevent penetration of objects into the cab and yet provide adequate windshield area for visability. Rollover structure **511**, as U-shaped reinforcing members, is built into the side walls and roof of the cab to protect the crew if the locomotive turns over in a derailment.

The entire cab **11** is built as a structural unit for attachment at a minimum number of points to the locomotive frame. These attachments are necessarily strong to protect cab integrity in a collision but during ordinary servicing requiring access to areas obstructed by the cab the entire cab can be easily removed. The cab has its own floor structure **513** and all locomotive controls and electronic equipment are mounted to the cab except perhaps air brake control as discussed hereinafter. Therefore, release of the cab from the frame requires disconnection of electrical and physical connections. If a standard air brake system is used, the air brake stand is designed to stay with the locomotive when the cab is pulled off so that the air brake control stand cannot be disassembled to remove the cab.

As shown in FIGS. **6** and **7**, all side and top panels **517** and **519** of the hood are designed to be removed in roof and wall sections. Ordinary daily servicing of the locomotive is facilitated by the panel construction **521** immediately above the driving wheels and cylinders. The bottom sections of the side panels are hinged at **523** to facilitate access to valve gear, lubricators, the throttles, air brakes, cylinders, grate, air duct grill and overhung brake rigging. Additional hatches are provided under the cab in both the power and support unit for air brake equipment, sand and batteries.

With reference to FIGS. **28–30**, the four coal openings **372** in the bottom of the box **50** are designed to have the minimum area consistent with a good flow of the coal and yet allow the sides **392** to close when a box is not entirely empty. Each box is equipped with lifting eyes **531** for transloading by a crane and hinged doors at the top for loading. Several of the coal packs could be loaded on a modified flat car for the journey to and from the mine with the doors opened at the top of the box. The boxes can be loaded as conventional railway hopper cars. Rugged construction is provided throughout so that the box can withstand the abuse it will take in loading at the mine and transloading on board the locomotive. Ample interior **370** is provided, and all parts of the pack are kept as simple and direct as possible. The pack is designed to be a standardized pack which could be fitted on any locomotive.

The main stoker motor **38**, as shown in FIG. **12**, is a water turbine motor powered by return water going to the support unit cooling assemblies or towers **110**. The main stoker turns the stoker screw shaft **123**, which through its universal couplings, rotates through its entire length in both power unit and support unit from the single power source. If the main stoker motor jams, if turning the coal screw requires additional power or if water is not flowing to the main stoker motor, an auxiliary reciprocating stoker motor **533** has a virtue of a steam piston engine in that it can exert high torque at low rpm when there is temporary obstruction in the coal screw. The coal screw and auxiliary stoker motor are adapted directly from standard practice on steam locomotives.

The modular coal packs are shown in FIGS. **8, 11** and **28–31**. The frame work beneath the pack is welded, and the structure serves as tracks for four steel plate doors **392** similar in construction to the sliding doors under a standard railway hopper car. The mechanism **396** to open the coal pack door is a permanent part of the power unit structure. The coal pack opening mechanism could be operated by power shafting or separate air motors could be provided to turn gears to engage teeth **1011** of the racks on the bottom of the floor sliding steel doors. In end view, the coal pack is designed to follow the clearance profile of the locomotive and the location of the coal pack in the support unit is designed to be non-critical. Each coal pack may contain a transverse strut member **1013** positioned near opening **372** to provide added reinforcement where the coal exits the coal pack.

The location of a coal pack, when set into the support unit could vary up to 2 inches and the door slides could still be operated adequately. The support unit contains a series of spaced support struts **1017**, which mate with and support the coal packs. Access doors **1015** are provided in the support unit at the coal pack areas shown in FIG. **8** and the hatches provide access to the door retracting mechanism and manual locking pins **1016** which hold the coal packs in place on board the support unit. After coal packs are loaded on the locomotive by crane, the sliding doors can be pulled and the coal will spill into the trough of the coal screw in the support unit. When the coal pack is to be changed whether it is empty or partially full, the bottom doors must be closed. The door operating mechanism slides are designed to close the doors against a partial load of coal in the box.

The makeup water tank **52** of approximately 10,000 gallons capacity is provided in the support unit **14** as shown in FIGS. **8–11**. FIG. **10** shows a cross-section of the water tank which forms the floor **271** under the water cooler assemblies and forms a tower **273** in the center of the support unit holding the water driven cooler fans **116**. The water tank is equipped with suitable baffles and support structure to have structural integrity. The makeup water tank may be filled from ground level by a pressure water fill **275**, one on each side of the locomotive as shown in FIG. **8**, or the tank may be filled by gravity from the roof. The gravity water fill caps **277** also provide pressure relief when the pressure water fill is being used. Water supplied to the locomotive is to be treated water. If not, a small chemical plant should be provided on board the support unit. Sophisticated modern water treatment is required to minimize boiler maintenance and to prevent corrosion of the entire water cycle system.

The support unit frame is a weldment of standard design and structure such as that found in a conventional tender or diesel locomotive.

The support unit trucks **46** are adapted directly from standard high speed trucks which were used under steam locomotive tenders. These trucks are suspended entirely on coil springs, and are equipped with roller bearings on all twelve journals. Truck mounted brakes are provided with two shoes per wheel. The truck centers **279** are chosen to give approximately equal lateral displacement of the end of the support unit frame where the frame joins the power unit. This is illustrated in FIG. **34**, where on the sharpest operating radius the overhang of both power unit and support unit at the rear corners is approximately equal.

The support unit cab **13** is identical in all respects to the power unit cab **11** and the locomotive can be operated equally well from either position and in either direction.

Although the present invention has been shown and described in terms of a preferred embodiment, it will be appreciated by those skilled in the art that changes or modifications are possible which do not depart from the inventive concepts described and taught herein. Such changes and modifications are deemed to fall within the purview of these inventive concepts.

For instance, an alternative embodiment **10'**, provided specifically for the purpose of increasing low speed tractive effort, shown in FIG. **36**, where like reference numerals denote similar elements to the embodiment of FIG. **1**. Since the majority of the elements are the same, only the differences will be described. The structure of the boiler **20** and accessories **24** and the machinery of the running gear **34** are identical in all respects to the first embodiment. Also, the cooling modules **42** and water storage area **40** and cooling fans **116** of the alternative embodiment are identical to the first embodiment. The alternative embodiment incorporates 8 driving axles **34** with four of these under the support unit **14** and four under the power unit **12**. High pressure steam is divided in its passage to four high pressure cylinders **88** located as fore and aft pairs on either side of the centerline of the power unit and extraction steam from these high pressure cylinders fills a receiver **162** which then passes from the power unit to the support unit where the steam divides again and supplies inlet steam into the four low pressure cylinders **166** similarly located as fore and aft pairs on either side of the centerline of the support unit **14**. In yet an additional embodiment of this same locomotive **10'N** the cylinders could be arranged in like manner to locomotive **10** on each of the power and support units. In that additional embodiment, each unit would have two high pressure and two low pressure cylinders.

The machinery of the embodiment of FIG. **36**, except for the layout of the cylinders **88, 166**, is identical to the embodiment of FIG. **1** so that at the upper end of the speed range there is no difference in machinery limit of the two locomotives. For improved operating capability of the alternative embodiment in the higher speed range, poppet valves may be used because of the ability of poppet valves to have more precise control steam flow at necessarily short cut-offs.

Because the support unit of the alternative embodiment has driving gear **24** mounted beneath the frame **30**, there is less vertical distance in the support unit to provide room for necessary equipment. There is not room for the same layout of condensing modules, water, and coal packs as found on the support unit of the first embodiment. Therefore the coal packs **50** are located on a separate articulated carrier **671** mounted between the power unit and support unit. This carrier has two conventional outside frame four-wheel trucks **673** and each truck is equalized by conventional means (as for example, the way in which a Southern Pacific AC-class steam locomotive had its outside-frame four wheel engine truck equalized with its adjacent driving group) into the driving gear **34** of the power drive immediately adjacent. Therefore, the weight carried by the coal pack carrier trucks is less affected by the amount of the coal carried in the packs, because, the coal pack carrier trucks **673** support a portion **675** of the power unit weight and a portion **677** of the support unit weight as well as the weight of the coal packs. The layout of driving gear and auxiliary wheels of the locomotive **10'** provides for excellent tracking characteristics in both directions of operation.

Further, it is contemplated that the teachings of the present invention may be applied to steam turbine electric locomotives. FIG. **37** illustrates a preferred embodiment, where like reference numerals denote like elements of the embodiment of FIG. **1**. For this reason only the differences will be described.

The locomotive, generally designated **10''**, is designed to adapt the gas producer combustion system of the present invention to a steam turbine electric drive. To provide the increased pressure steam required for turbine operation, a gas producer adaptation is made to a standard form of water-tube firebox **325** with a firetube barrel. Operating pressure is 600 psi with final steam temperature approximately 900° F. The superheater **140**, economizer **128**, feedwater heater **124**, multicyclones **326**, ID fans **152** and support systems are adapted directly from the power unit of the embodiment of FIG. **1**. The steam turbine electric transmission **681** located at the back of the power unit is adapted directly from known locomotive systems. Likewise, the turbine **685** is a known multi-stage axial turbine. One such turbine system was used on the Norfolk and Western #2300 locomotive in past practice. Eight driving axles are provided under the power unit by means of two standard Electromotive Cor. type DD trucks **683** with each truck carrying four standard EMC type traction motors controls and electrical gear follow conventional practice. The support unit (not shown) is identical in all respects to that of the embodiment of FIG. **1**, except that the jet condensers **86** are relocated to the support unit in a space between the cooling area **42** and the coal pack area **36**. Electric motors drive the circulating pumps associated with the jet condensers, with current supplied by the main generator driven by the steam turbine. Therefore, approximately 6 ft. of additional space is provided on the support unit for the eductor condensers.

The water-tube firebox with firetube barrel boiler provide steam sufficient to produce 4,500 shaft HP from the turbine. This power shaft HP is sufficient to provide 3900 to 4000 drawbar HP to the rail at speeds between 10 and 40 mph. The power unit is capable of exerting at least 140,000 lbs. of tractive effort continuously up to the limit of the boiler. A virtue of the electric drive is that the support unit axles may be provided with traction motors, and, if so, the low speed continuous tractive effort could be significantly increased by at least 15,000 lbs. of continuous tractive effort for each support unit axle provided with a traction motor.

The boiler **24** was described in the context of the embodiment of FIG. **1** and additional features in locomotive **10**″ include two stages of superheating. One stage is a standard Type-E superheater at the front of the firetube barrel and the additional stage of superheater **687** is provided in the furnace combustion chamber **132** by conventional superheater loops from the main steam drums.

A standard Detroit CC shuffle grate is employed, except that the shuffle grate carries the ashes in the direction away from the stoker feed **130**. Ashes are dumped directly by gravity into an ash box **332** under the locomotive frame. This ash box could be serviced by a forklift truck at servicing stops.

Fly ash is collected at the front of the locomotive in the same fashion as the embodiment of FIG. **1** and collected cinders are conveyed by steam or air back to a fly ash box **330** located under the locomotive frame next to the main ash box.

Some steam is tapped from the superheater header **133** to run the ID fan **152** and the steam is then passed back to run some of the auxiliaries. The main steam flow is from the superheater header back to the inlet of the axial turbine **695**. The steam then flows out of the axial turbine to a flexible exhaust steam connection to the support unit into the twin eductor condensers **86** mounted on the support unit. All other aspects of the steam cycle are substantially identical to the embodiment of FIG. **1**.

From the above, it is apparent that many modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A locomotive comprising:

a water tank holding a quantity of water;

means for generating steam;

first conveying means for conveying said water from said tank to said steam generating means for conversion to steam;

steam engine means for converting said steam into a mechanical motion, said steam engine means releasing portions of said steam during said conversion;

second conveying means for conveying said steam from said steam generating means to said steam engine means;

means responsive to said mechanical motion produced by said steam engine means for causing said locomotive to move in a desired direction;

third conveying means for conveying water from said water tank;

steam conveying means for conveying said released steam from said steam engine;

condensing means, operative to receive water from said third conveying means and to receive said released steam from said steam conveying means, for condensing said released steam by intermingling said steam with said water from said water tank;

cooling means for cooling water passed therethrough;

fourth conveying means for conveying said water from said condensing means to said cooling means; and

fifth conveying means for conveying said cooled water from said cooling means to said water tank.

2. The locomotive of claim **1**, wherein said condensing means comprises eductor condensing means.

3. The locomotive of claim **1**, wherein said cooling means comprises:

at least one heat-exchanging means through which said water from said first condensing means passes; and

means for directing air from atmosphere through said heat-exchanging means to provide air for cooling the water passing through said heat-exchanging means.

4. The locomotive of claim **3**, wherein said cooling means further comprises:

fan means for drawing said air from atmosphere through said heat-exchanging means.

5. The locomotive of claim **4**, wherein said cooling means further comprises:

deflecting means, secured to said at least one heat exchanging means, for directing said air passing through said heat exchanging means towards said fan means.

6. The locomotive of claim **1**, wherein said steam generating means comprises:

a gas producer furnace for producing flue gases from coal;

a firetube boiler for receiving said cooling water and said flue gases, wherein said flue gases convert said cooling water into steam.

7. The locomotive of claim **6**, wherein said gas producer furnace comprises:

a furnace chamber having a bottom;

a moving grate positioned for oscillating movement on the bottom of said furnace chamber;

a wind box defined below said grate;

means for introducing a source of primary air into said wind box;

an injector positioned below the grate within said wind box;

means for conveying fuel onto said grate to define a fuel bed;

a first area defined in said furnace chamber wherein said coal burns in the primary air supplied under said grate to create products of a first stage of combustion;

a second area defined in said furnace chamber and located above said first area within which said products of a first stage of combustion are burned to completion to create said flue gases;

means for injecting steam into said second area for enhancing said combustion;

means for introducing secondary heated air into said second area for creating a cyclonic path for said flue gases; and

means for moving said flue gases in said cyclonic path into said first tube means.

8. The locomotive of claim **7** further comprising an ash pan positioned below said moving grate for receiving particles of combustion;

cyclone separating means;

means for moving said particles of combustion from said ash pan to said cyclone separating means; and

an ash package for receiving the particles of combustion from said cyclone separator.

9. The locomotive of claim **7** further comprising air turbulator means for introducing swilling air into said second area of said furnace chamber.

10. The locomotive of claim **7** further comprising an inlet air damper through which air enters into said furnace chamber;

first and second pre-heaters through which said air from said air damper passes, each of said pre-heaters adapted to utilize extraction steam to heat said air from said air damper; and

means for dividing said heated air into a plurality of paths, including a first path which passes heated air into said wind box under said furnace grate, and

a second path which passes air above said burning fuel bed in order to create said cyclonic path.

11. The locomotive of claim **6**, wherein said furnace produces a flue gas containing particles of combustion, and wherein said steam generating means further comprises:

receiving means for receiving said flue gas with said particles of combustion from said firetube boiler;

separating means for separating said flue gas from said particles of combustion in said receiving means;

means connected to said separating means for releasing said separated flue gas to atmosphere; and

means connected to said separating means for collecting and storing said particles of combustion for subsequent disposal.

12. The locomotive of claim **11**, wherein said separating means comprises at least one cyclone separator.

13. The locomotive of claim **11**, wherein said receiving means comprises a flue gas plenum.

14. The locomotive of claim **11**, wherein said means for releasing said flue gas to atmosphere comprises a fan, and means for connecting said fan to an output of said at least one cyclone separator.

15. The locomotive of claim **14**, wherein said means for releasing said flue gas to atmosphere further comprises a steam turbine for operating said fan, and means for conveying steam from said steam generating means to said turbine.

16. The locomotive of claim **11**, wherein said means for collecting the particles of combustion is a fly ash receptacle.

17. The locomotive of claim **16**, wherein said fly ash receptacle is removably mounted in said locomotive.

18. A locomotive comprising:

a water tank for holding a quantity of water;

furnace means for producing flue gas from coal, said flue gas containing particles of combustion;

steam producing means receiving said flue gas containing particles of combustion for producing steam;

means for conveying said flue gas containing particles of combustion to said steam producing means;

means for conveying said water from said water tank to said steam producing means;

cylinder means including at least one piston for converting said steam into a reciprocating mechanical motion of said piston, said cylinder means releasing portions of said steam during said conversion;

means for conveying said steam from said steam producing means to said cylinder means;

means connected to said piston and responsive to said reciprocating motion produced by said piston for causing said locomotive to move in a desired direction;

condensing means, receiving said released steam from said cylinder means, for converting said steam to water;

means conveying said released steam from said cylinder means to said condensing means;

cooling means connected to said condensing means to receive said water from said condensing means for cooling said water;

means connected to said cooling means for conveying said cooled water from said cooling means to said water tank;

means for receiving said flue gas containing particles of combustion from said steam producing means;

separating means for separating said flue gas from said particles of combustion in said receiving means;

means connected to said separating means for releasing said separated flue gas to atmosphere; and

means connected to said separating means for collecting and storing said particles of combustion for subsequent disposal.

19. The locomotive of claim **18**, wherein said steam producing means includes a firetube boiler for receiving said water from said water tank and said flue gases, wherein said flue gases convert said water into steam.

20. The locomotive of claim **18**, wherein said condensing means comprises eductor condensing means.

21. The locomotive of claim **18**, wherein said separating means comprises at least one cyclone separator.

22. The locomotive of claim **18**, wherein said receiving means comprises a flue gas plenum.

23. The locomotive of claim **18**, wherein said cooling means comprises:

at least one heat-exchanging means through which said water from said first condensing means passes; and

means for directing air from atmosphere through said heat-exchanging means to provide air for cooling the water passing through said heat-exchanging means.

24. The locomotive of claim **23**, wherein said cooling means further comprises:

fan means for drawing said air from atmosphere through said heat-exchanging means.

25. The locomotive of claim **24**, wherein said cooling means further comprises:

deflecting means, secured to said at least one heat exchanging means, for directing said air passing through said heat exchanging means towards said fan means.

26. The locomotive of claim **18**, wherein said means for releasing said flue gas to atmosphere comprises a fan, and means for connecting said fan to an output of said at least one cyclone separator.

27. The locomotive of claim **26**, wherein said means for releasing said flue gas to atmosphere further comprises a steam turbine for operating said fan, and means for conveying steam from said steam producing means to said turbine.

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