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(54) Two-stroke turbocharged internal combustion engine having 14 cylinders in a single row

(57) A two-stroke turbocharged internal combustion engine has 14 cylinders in a single row and a scavenge air system with at least one elongated scavenge air receiver. The engine has a firing sequence (n1 - n14) of the engine cylinders C1-C14, so that at least the following four requirements a) to d) are met :

for the 4th order gas pulsation

$$a)\ V_{GAS}(4) = \left| \sum_{n=1}^{n=14} F(n) \cdot (\sin(4(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(4(\omega t + \varphi_n))) \right| < 2.5$$

for the 5th order gas pulsation

$$b)\ V_{GAS}(5) = \left| \sum_{n=1}^{n=14} F(n) \cdot (\sin(5(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(5(\omega t + \varphi_n))) \right| < 2.0$$

for the 6th order gas pulsation

$$c)\ V_{GAS}(6) = \left| \sum_{n=1}^{n=14} F(n) \cdot (\sin(6(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(6(\omega t + \varphi_n))) \right| < 2.1$$

for the 7th order gas pulsation

$$d)\ V_{GAS}(7) = \left| \sum_{n=1}^{n=14} F(n) \cdot (\sin(7(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(7(\omega t + \varphi_n))) \right| < 2.2$$

where n is the cylinder number, φ_n is the firing angle for the cylinder n, F(n) is a weighting function linearly interpolated with respect to the position of the cylinder between F(1) = 1 at cylinder C1 and F(14) = -1 at cylinder C14, and || identifies the length of the vector.

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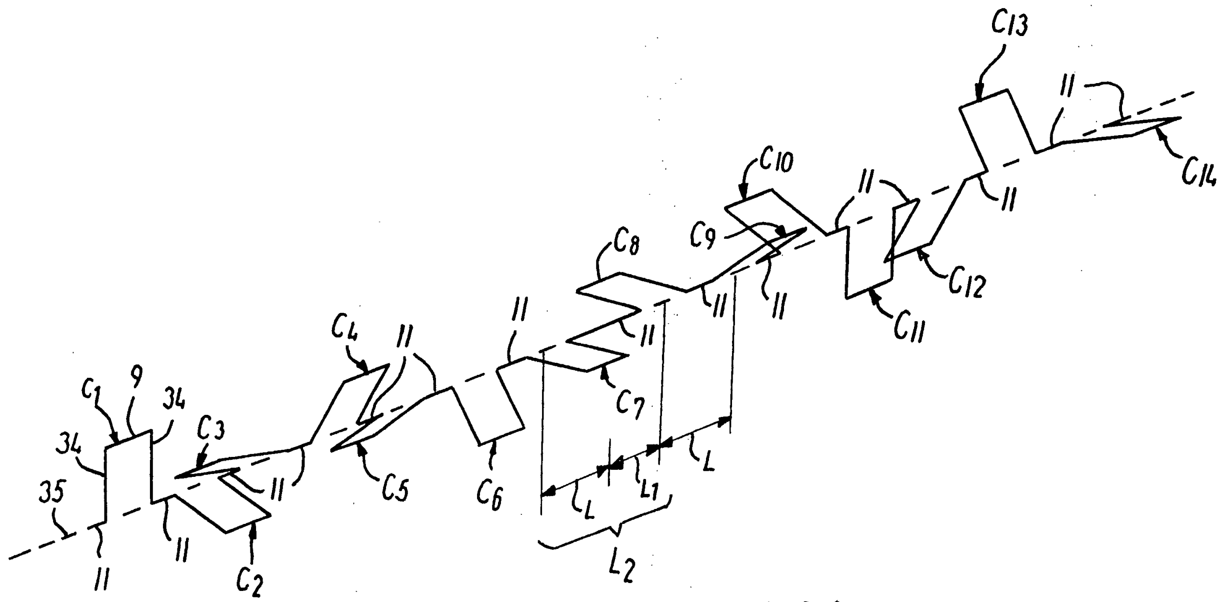
C13
11
C14
C10
11
11
C9
C12
C8
11
11
C11
11
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C4
11
11
C7
C1
9
34
34
C3
L
35
11
C5
C6
L
L1
11
11
C2
L2

FIG. 3

Description

[0001] The present invention relates to a two-stroke turbocharged internal combustion engine having 14 cylinders in a single row, at least one exhaust gas receiver, at least two turbochargers, and a scavenge air system with at least one elongated scavenge air receiver, each cylinder having a scavenge air inlet connected to the scavenge air receiver and an exhaust passage leading into the at least one exhaust gas receiver, said turbochargers being connected with the exhaust gas receiver on its turbine side and with the scavenge air system on its compressor side, which engine has a firing sequence (n1 - n14) of the engine cylinders C1-C14.

[0002] The engine with the scavenge air receiver uses so-called constant-pressure turbocharging which is based on the principle that the exhaust gas flow pulses from the individual cylinders are equalized by passing the exhaust gas from the cylinders out through the associated exhaust passage to a common exhaust receiver which is an elongate pressure vessel of a sufficiently large volume to allow some expansion of the many high intensity gas flow pulses from the cylinders into a common gas flow at an even pressure.

[0003] The turbine part of the turbochargers receives exhaust gas at a constant pressure when the engine load is constant, and this increases the efficiency of the turbochargers and results in a constant supply of inlet air from the compressor part of the turbochargers to the scavenge air system on the inlet side of the engine cylinders. Pressure fluctuations in the exhaust gas receiver can cause fluctuations in the power of the turbochargers and thus uneven and varying charging air deliveries to the charging air system.

[0004] The supply of scavenge air to the inlet side of the engine influences the filling of the cylinders with charging air and thus the combustion process in the cylinders and the power developed at the combustions. The in-line engine with 14 cylinders has a long length and thus a long scavenge air receiver. The pressure variations in the charging air supplied from the turbochargers can to some degree cause pressure variations in the scavenge air receiver. However, larger pressure fluctuations in the scavenge air receiver are created by the pattern in which the cylinders consume scavenge and charging air from the scavenge air receiver.

[0005] It is a problem in a 14 cylinder two-stroke in-line engine that gas pressure fluctuations in the at least one scavenge air receiver cause differences in the loading of the cylinders with charging air. These differences occur between cylinders located at a distance from one another and cause undesired variations in the power developed at combustion in the cylinders, and this influences the control of the cylinders, in particular in respect of the fuel dosage.

[0006] The object of the present invention is to minimize or avoid fluctuations in fuel dosage to the engine cylinders caused by variations in the filling of the cylinders with charging air, when the engine is running at constant load.

[0007] In view of this, the two-stroke constant-pressure turbocharged internal combustion engine according to the present invention is characterized in that the fourteen cylinders have a firing sequence (n1 - n14) so that at least the following four requirements a) to d) are met

for the 4th order gas pulsation

$$\text{a) } V_{GAS}(4) = \left| \sum_{n=1}^{n=14} F(n) \cdot (\sin(4(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(4(\omega t + \varphi_n))) \right| < 2.5$$

for the 5th order gas pulsation

$$\text{b) } V_{GAS}(5) = \left| \sum_{n=1}^{n=14} F(n) \cdot (\sin(5(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(5(\omega t + \varphi_n))) \right| < 2.0$$

for the 6th order gas pulsation

$$\text{c) } V_{GAS}(6) = \left| \sum_{n=1}^{n=14} F(n) \cdot (\sin(6(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(6(\omega t + \varphi_n))) \right| < 2.1$$

for the 7th order gas pulsation

$$\text{d)}\ V_{GAS}(7) = \left|\sum_{n=1}^{n=14} F(n)\cdot(\sin(7(\omega t+\varphi_n)) + \sqrt{-1}\cdot\cos(7(\omega t+\varphi_n)))\right| < 2.2$$

where n is the cylinder number, φ_n is the firing angle for cylinder n, F(n) is a weighting function linearly interpolated with respect to the position of the cylinder between F(1) = 1 at cylinder C1 and F(14) = -1 at cylinder C14, and || identifies the length of the vector. The length of the vector is calculated in the traditional manner as the square root of sum of the second power of the resulting sine component added to the second power of the resulting cosine component.

[0008] When the firing sequence of the 14 cylinder in-line engine complies with these requirements the primary source for formation of pressure fluctuations in the scavenge air receiver has been minimized to such a low level that the fuel dosing to the cylinders is mainly unaffected by scavenge air pressure fluctuations. The firing sequences fulfilling the requirements result in that the cylinders consume scavenge and charging air from the scavenge air receiver in sequences that do not create too large pressure fluctuations of the air in the scavenge air receiver.

[0009] In a preferred embodiment the fourteen cylinders have a firing sequence (n1 - n14) so that the following requirement e) is also met

$$\text{e)}\ V_{Nick}(1) = \left|\sum_{n=1}^{n=14} F(n)\cdot((\sin(\omega t+\varphi_n) + \sqrt{-1}\cdot\cos(\omega t+\varphi_n))\right| < 2.5$$

where n is the cylinder number, φ_n is the firing angle for cylinder n, F(n) is a weighting function which is F(1) = 0 at cylinder C1 and F(n) = F(n-1) + ((distance from the centre line of cylinder C_{n-1} to the centre line of cylinder C_n)/(nominal distance between cylinders)), and || identifies the length of the vector. The nominal distance between cylinders is the distance between cylinders having only a single main bearing between the cylinders, typically the distance between the centre lines of cylinders C1 and C2. In a 14 cylinder engine the crankshaft is typically manufactured in two parts that are joined, typically by being bolted together, in between two cylinders. There are two main bearings between these two cylinders, which are consequently separated by a distance larger than said nominal distance.

[0010] A long in-line engine as a 14 cylinder two-stroke engine is typically used as a propulsion engine in a ship. The advantages obtained by designing the firing sequence in accordance with requirements a) to d) are further enhanced by also making requirement e) be fulfilled. Requirement e) furthermore provides the advantage that the so-called nick-moments will be diminished. Nick-moments are a weighted summation over the cylinders of the vertical forces acting at the tie rods and at the main bearings. The nick-moments tend to induce an undesired vibration of the engine and ship hull in the vertical plane.

[0011] In a further embodiment the fourteen cylinders have a firing sequence (n1 - n14) so that the following requirement f) is also met

$$\text{f)}\ V_{Nick}(2) = \left|\sum_{n=1}^{n=14} F(n)\cdot((\sin(2(\omega t+\varphi_n)) + \sqrt{-1}\cdot\cos(2(\omega t+\varphi_n)))\right| < 6.0$$

where n is the cylinder number, φ_n is the firing angle for cylinder n, F(n) is a weighting function which is F(1) = 0 at cylinder C1 and F(n) = F(n-1) + ((distance from the centre line of cylinder C_{n-1} to the centre line of cylinder C_n)/(nominal distance between cylinders)), and || identifies the length of the vector. The second order nick moment is a weighted summation over the cylinders of the second order vertical forces acting at the tie rods and at the main bearings. These second order nick moments can induce undesired vertical vibrations. It is also possible to make an engine with fourteen cylinders with a firing sequence (n1 - n14) so that both the above mentioned requirements e) and f) are fulfilled, and this minimizes the influence of nick moments on vertical hull vibration. Preferably, Vnick(2) is less than 3.0 and more preferably less than 2.0.

[0012] In the most preferred embodiment the fourteen cylinders have a firing sequence (n1 - n14) so that

a) for the 4th order gas pulsation Vgas(4)< 1,
b) for the 5th order gas pulsation Vgas(5)< 2,
c) for the 6th order gas pulsation Vgas(6)< 2,
d) for the 7th order gas pulsation Vgas(7)< 2.2,
e) for the 1st order nick-moments Vnick(1)< 1.5,

f) for the 2^{nd} order nick-moments Vnick(2)< 1.5.

The firing sequences fulfilling these criteria provides the engine with exceptionally fine running conditions in relation obtaining even pressure in the scavenge air receiver along the complete length thereof, and additionally the vibration level is generally very fine in the sense that all of the traditionally considered vibration levels are within acceptable limits. Less than 600 even firing sequences fulfil these criteria, out of the 6,227,020,800 possible even firing sequences for the 14 cylinder engine.

[0013] The firing sequence can be even in the sense that the turning angle of the crankshaft between the firing of two consecutive cylinders is 360°/14. This fixed size angle is used for all cylinders in the engine. If there is a special problem in a particular engine installation it is also possible to fine-tune the vibration pattern by using a firing sequence which is uneven in the sense that the turning angle of the crankshaft between the firing of at least two pairs of consecutively firing cylinders is different from 360°/14.

[0014] Examples of embodiments of the present invention are described in more detail in the following with reference to the highly schematic drawings, on which

Fig. 1 is a sectional view of a two-stroke engine with 14 cylinders according to the present invention,
Fig. 2 is a side view of the engine in Fig. 1,
Fig. 3 is a perspective view of a crankshaft for the engine in Fig. 1,
Fig. 4 is an illustration of the firing sequence for the cylinders pertaining to the crankshaft of Fig. 3,
Fig. 5 is an illustration of gas pulsations of different modes in the scavenge air receiver, and
Fig. 6 is an illustration of forces causing nick moments.

[0015] In Fig. 1 is seen the cross-section through a large two-stroke constant-pressure turbocharged internal combustion engine of the crosshead type, having 14 cylinders. The engine can e.g. be of the make MAN B&W Diesel and the type MC or ME, or of the make Wärtsilä of the type Sulzer RT-flex or Sulzer RTA. The cylinders can have a bore in the range of e.g. 60 to 120 cm, preferably from 80 to 120 cm, and more preferably from 95 to 120 cm. The engine can e.g. have a power in the range of 3000 to 8500 kW per cylinder, preferably from 4000 to 8000 kW, such as at least 5.000 kW per cylinder. Each cylinder C1-C14 typically has a cylinder liner 1 with a row of scavenge air ports 2 in its lower end and a cylinder cover 3 with an exhaust valve 4 located in the top of the cylinder.

[0016] A piston 5 is mounted on a piston rod 6, which via a crosshead 7 and a connecting rod 8 is connected with a crank pin 9 on a crankshaft 10. The crankshaft journal 11 is located in a main bearing mounted in a bedplate 12.

[0017] The crosshead is supported in the transverse direction by guide shoes 13 sliding on vertically extending guide planes. The guide planes are fixed to the stationary A-frame 14 of the engine. A cylinder section 15 is mounted on top of the A-frame.

[0018] The cylinder cover 3 is fixed to the cylinder section by cover studs 16. Tie-rods 17 extend from the cylinder section down to the bedplate and they fix the cylinder section 15 to the bedplate 12. There are typically four tie-rods 17 acting on each cylinder section, and the sum of the downward forces from the tie-rods exceeds the upwards directed force on the cylinder cover caused by the maximum pressure developed by the combustion in the combustion chamber in the cylinder.

[0019] An exhaust gas duct 18 extends from the individual cylinder in the area of the exhaust valve and opens out into an exhaust gas receiver 19 that is common to a number of cylinders. The engine may have only a single exhaust gas receiver which is common to all cylinders, or it can have a plurality of exhaust gas receivers, such as two or three, located end-to-end in extension of each other and typically interconnected through gas flow passages.

[0020] The exhaust gas receiver is a pressure vessel with a circular cylindrical cross-section. The exhaust gas duct 18 is extending into the exhaust receiver 19 and delivers the exhaust gas from the pertaining combustion chamber when the exhaust valve is open. In the exhaust gas receiver pressure variations caused by the exhaust gas pulses emitted from the exhaust gas ducts are equalized to a more even pressure.

[0021] Four turbochargers 20 are connected to the exhaust gas receiver 19 in such a manner that the exhaust gas can flow via exhaust passages 21 through the turbine part 22 of the turbocharger where it acts as a drive medium for the turbine wheel, which is mounted on a drive shaft for a compressor wheel located in a compressor part 23 of the turbocharger. The compressor part 23 can deliver compressed air in direction of arrow A via an air flow passage 24 and possibly an inlet air cooler 25 to a scavenge air system 26.

[0022] The scavenge air system comprises at least one scavenge air receiver 27 common to several or all cylinders, and for the individual cylinder a flow passage 28 that connects an inlet air chamber 29 with the scavenge air receiver so that inlet air can flow in direction of arrow B to fill the inlet air chamber with air to be consumed by the cylinder. The scavenge air receiver is a pressure vessel with a cylindrical shape that is circular in cross-section. Check-valves 31 are provided at the air inlets in the lower portion of scavenge air receiver 27.

[0023] The inlet air is called both scavenge air and charging air. However, the inlet air is one and the same. In a two-stroke engine there is needed inlet air to scavenge (clean) the combustion chamber for combustion products while the exhaust valve is open and inlet air to charge the cylinder with air for the next combustion process after closure of the exhaust valve. The inlet air chamber 29 surrounds the lower portion of cylinder liner 1 having scavenge air ports 2.

[0024] During the combustion stroke of a two-stroke cycle piston 5 is moved in downward direction until it is positioned in the lowermost part of cylinder liner at the bottom dead centre position in which the upper surface of the piston is located below scavenge air ports 2. At the moment when the piston during this downward movement passes the scavenge air ports, air from inlet air chamber 29 flows into the cylinder and causes a pressure drop in said chamber and also in the scavenge air receiver in the local area near flow passage 28 leading into the cylinder.

[0025] The air consumptions and associated local pressure drops in the scavenge air receiver occur at the flow passages 28 that are distributed along the length of the scavenge air receiver. The cylinders consume air in a sequential manner at points in time that depend on the firing sequence of the engine. As the delivery of inlet air to the cylinders varies both in time and place, the air inside the scavenge air receiver may be made to fluctuate. The natural frequencies of longitudinal gas pressure waves inside the scavenge air receiver depend, among other things, on the length of the receiver.

[0026] The scavenge air receiver illustrated in Fig. 5 is common to all cylinders on the engine, and it consequently extends along the complete length of the engine. The lowest natural frequency of the air fluctuations in the scavenge air receiver corresponds to so-called 1st mode gas pulsations, in which the pressures at the receiver ends are in counterphase and the largest velocity changes occur in the middle of the receiver. The 1st mode gas pulsation is illustrated by the curve a in Fig. 5. The 2nd mode gas pulsation is illustrated by the curve b in Fig. 5. It appears that the 1st mode gas pulsation has a single node 32, the 2nd mode gas pulsation two nodes 32, and so forth with one additional node for every increase of the mode number.

[0027] The ability of the sequential consumption of air to excite gas dynamic oscillations in the scavenge air receiver depends on the firing sequence of the engine and the current engine speed. If the frequency of the pressure waves coincides with a natural frequency for a specific mode of gas pulsations, rather large air pressure fluctuations can occur. These undesired pressure fluctuations may affect the filling of the cylinders, in particular the cylinders located at the largest distances from the nodes 32 in the relevant vibration order.

[0028] It is of course possible to divide the scavenge air receiver into several receiver sections located one after the other in an end-to-end relationship. Although this changes the length of the individual scavenge air receiver, it does not solve the problem of pressure fluctuation firstly because the fluctuations will still occur and secondly because the division at the same time make possible variations in the air amounts delivered from the individual turbochargers more dominant as such variations cannot be equalized as in a single scavenge air receiver common to all cylinders.

[0029] By choosing the firing sequence in accordance with the above mentioned requirements a) to d) the sequence in which the cylinders consume air from the scavenge air receiver is such that the variations in filling of cylinders due to scavenge air pulsations are so small that they do not cause disturbing adjustments in the fuel setting for the cylinders.

[0030] Examples of firing sequences fulfilling the requirements a) through f) can be given as follows:

No.	Firing sequence for cylinders C1 to C14
1	1-4-9-14-7-2-6-11-12-5-3-8-10-13
2	1-4-9-14-7-2-6-12-11-5-3-8-10-13
3	1-5-8-14-7-2-6-11-12-4-3-9-10-13
4	1-5-8-14-7-2-6-11-13-4-3-9-10-12
5	1-5-8-14-7-2-6-13-11-4-3-9-10-12
6	1-5-9-14-7-2-6-11-12-4-3-8-10-13
7	1-5-11-12-6-2-8-10-13-3-4-7-14-9
8	1-6-9-14-5-2-7-12-11-4-3-8-13-10
9	1-6-9-14-5-2-7-13-11-3-4-8-12-10
10	1-6-10-14-2-5-7-12-11-3-4-9-13-8
11	1-6-11-13-2-5-7-14-9-3-4-10-12-8
12	1-6-11-14-2-5-7-12-10-3-4-9-13-8
13	1-6-11-14-2-5-7-12-10-4-3-9-13-8
14	1-6-11-14-2-5-7-13-9-3-4-10-12-8
15	1-6-11-14-2-5-7-13-10-3-4-9-12-8
16	1-6-13-11-4-2-8-14-7-5-3-12-10-9
17	1-6-13-11-4-2-9-14-7-5-3-12-10-8
18	1-7-10-14-2-5-6-12-11-3-4-9-13-8

(continued)

No.	Firing sequence for cylinders C1 to C14
19	1-7-13-11-4-2-9-14-6-5-3-12-10-8
20	1-8-10-13-2-4-9-14-7-3-5-11-12-6
21	1-8-11-12-2-4-9-14-7-3-5-10-13-6
22	1-8-11-12-2-5-7-13-9-3-4-10-14-6
23	1-8-12-9-5-2-10-13-7-4-3-14-11-6
24	1-8-12-10-4-2-11-13-6-5-3-14-9-7
25	1-8-12-10-5-2-9-14-7-4-3-13-11-6
26	1-8-13-9-2-4-11-12-6-5-3-14-10-7
27	1-8-13-9-4-2-11-12-6-5-3-14-10-7
28	1-9-12-8-5-2-11-13-7-4-3-14-10-6
29	1-9-12-10-2-3-13-11-6-4-5-14-8-7
30	1-9-12-10-2-3-13-11-6-5-4-14-8-7
31	1-9-12-10-3-2-13-11-6-4-5-14-8-7
32	1-9-12-10-4-2-11-13-6-3-5-14-8-7
33	1-10-11-9-4-2-12-13-5-3-6-14-8-7
34	1-10-11-9-4-2-13-12-5-3-6-14-8-7
35	1-10-12-9-2-4-13-11-5-3-6-14-8-7
36	1-10-13-8-2-4-12-11-7-3-5-14-9-6
37	1-11-10-9-4-2-12-13-5-3-6-14-8-7
38	1-12-10-9-2-4-13-11-5-3-7-14-8-6
39	1-12-11-8-2-4-13-10-7-3-6-14-9-5
40	1-12-11-8-2-5-13-10-6-3-7-14-9-4
41	1-13-10-8-2-5-12-11-6-3-7-14-9-4
42	1-13-10-8-2-6-12-11-5-3-7-14-9-4
43	1-14-10-8-2-6-12-11-5-3-7-13-9-4
44	1-14-11-6-2-8-12-10-4-3-9-13-7-5

[0031] Other firing sequences may also fulfil the requirements, and consequently the firing sequences stated are to be considered as preferred but nonlimiting examples of firing sequences for the 14 cylinder engine.

[0032] The following firing sequences fulfil the requirements of claim 5 a) < 1, b) < 2, c) < 2, d) < 2.2, e) < 1.5, f) < 1.5:

45	1-9-14-8-2-4-11-13-5-3-7-12-10-6
46	1-5-10-14-6-2-7-12-11-4-3-8-13-9
47	1-6-14-10-5-2-9-13-8-3-4-11-12-7
48	1-5-11-12-7-2-6-14-10-4-3-8-13-9
49	1-5-11-12-6-2-7-14-10-3-4-8-13-9
50	1-8-13-9-4-2-10-14-6-3-5-12-11-7
51	1-6-11-12-5-2-7-14-10-3-4-9-13-8
52	1-5-12-11-6-2-7-13-10-3-4-8-14-9

[0033] The following firing sequences fulfil the requirements a) < 1, b) < 1, c) < 1, d) < 1, e) < 1, f) < 1:

53	1-8-14-9-2-4-11-12-7-3-5-13-10-6
54	1-8-13-9-4-2-11-14-5-3-6-12-10-7
55	1-8-14-9-2-4-12-11-7-3-5-13-10-6

[0034] In the mentioned firing sequence No. 1 the cylinders C1 to C14 fire in the sequence 1 4 9 14 7 2 6 11 12 5 3 8 10 13. The firing sequence is implemented in the engine by the making the crankshaft 10 with crank throws 33 pointing in the angular pattern required for obtaining the firing sequence. The firing sequence is determined by the design of the crankshaft. Fig. 3 illustrates the pattern required for firing sequence No. 1 as an even firing sequence, viz. a firing sequence with a regular (even) angular interval of 360°/14 between the firings. Each crank throw 33 comprises two crank arms 34 and the crank pin 9, and the crank shaft journals 11 join the crank throws into a complete crank shaft. The crankshaft journals are aligned along a centre line 35 of the crankshaft and they are supported in main bearings in bedplate 12.

[0035] The distance 1 between the cylinders is constant through out the crankshaft illustrated in Fig. 3, except between cylinders C7 and C8 where the distance is 12 = 1 + 11, that is normal distance between cylinders plus an additional length 12 caused by the presence of two main bearings and an intermediate crankshaft joint, such as a flange connection where two crankshaft sections are joined by bolting. The crankshaft can suitably be divided into two sections in order to reduce the weight of the individual section. This facilitates lifting of the crankshaft onto the bedplate during assembly of the engine and it also facilitates manufacturing of the crankshaft, as the complete crankshaft of a 14 cylinder engine of the relevant size can have a weight well above 250 t. The distance 12 between the cylinders located at the joint is larger than the distance 1 between the other cylinders. It is also possible to locate the crankshaft joint between cylinders C8 and C9.

[0036] The engine can be an electronically controlled engine without a camshaft for activating fuel pumps and exhaust valves, e.g. an engine of the type ME. If the engine is of a traditional type with a camshaft, the camshaft can be driven from the crankshaft via a chain drive or a gearing, which suitably can be located between the cylinders separated by the larger distance 12.

[0037] The respective angles between the crank throws 33 of the crankshaft of Fig. 3 are also illustrated in Fig. 4. It is also possible to use irregular firing sequences, viz. a firing sequence that is uneven in the sense that the angular interval between the firings of at least two pairs, and possibly several pairs, of consecutively firing cylinders deviates from 360°/14. A deviation of only a few degrees can result in a different vibration pattern in the engine. Such irregular firing sequences can be useful for fine tuning of the resulting vibration characteristics of the engine. With respect to gas pulsations in the scavenge air receiver it is the firing sequence as such that is of importance for obtaining the advantageously low level of gas pulsations and not whether the firing sequence is regular or irregular.

[0038] The calculation of whether a particular firing sequence fulfils the individual requirements a) to d) and the further requirements e) and/or f) is typically performed electronically by a computer program such as PROFIR developed by MAN B&W Diesel or such as a textbook program as disclosed in "Die Verbrennungskraftmaschine" of H. Maass/H. Klier and K.E. Hafner/H. Maass, published by Springer-Verlag, Wien, New York.

[0039] The calculations are in the following exemplified with respect to the 14 cylinder engine illustrated in Fig. 2. The engine is of the make MAN B&W Diesel and the type MC, more specifically 14K98MC, having a cylinder bore of 0.98 m and a nominal cylinder distance of 1 = 1.75 m. The total length between the vertical centre lines of cylinders C1 and C14 is 23.99 m, and a chain drive is located between cylinders C7 and C8.

[0040] The additional length 11 between C7 and C8 is 1.24 m so that the resulting distance between cylinders C7 and C8 is 12 = 2.99 m. With the above mentioned firing sequence No. 1, 1 4 9 14 7 2 6 11 12 5 3 8 10 13, the following values are calculated.

[0041] Firing angles for cylinders C1 to C14: 0°, 128.6°, 257.1°, 25.7°, 231.4°, 154.3°, 102.9°, 282.9°, 51.4°, 308.6°, 180.0°, 205.7°, 334.2°, and 77.1°.

[0042] For the calculation of the gas pulsations the following values of F(n) are found by linearly interpolation with respect to the position of the cylinder between F(1) = 1 at cylinder C1 and F(14) = -1 at cylinder C14 : F(1)=1, F (2) =0.85411, F(3)=0.70821, F(4)=0.56232, F(5)=0.41642, F(6)=0.27053, F(7)=0.12464, F(8)= -0.1246, F(9)= -0.2705, F (10) = -0.4164, F(11)= -0.5623, F(12)= -0.7082, F(13)= -0.8541, and F(14)= -1. The position of the cylinder is calculated as the distance of the cylinder Cn from the cylinder C1 in the longitudinal direction of the engine divided by the total distance between the centre lines of cylinders C1 and C14. F(n) is consequently equal to 1 - 2 x (distance of cylinder Cn from cylinder C1)/(total distance from cylinder C1 to cylinder C14).

[0043] With respect to the value of ωt in the vector summation of equations a) to f) the length of the vector can be calculated with the value t=0, as the length of the resulting vector is independent of time.

[0044] With respect to the value for the 4th order gas forces stipulated in requirement a) the sine components multiplied with F(n) for the respective cylinders are the following: C1=0, C2= 0.37058, C3= -0.5537, C4= 0.54822, C5= -0.1807, C6= -0.2637, C7=0.09744, C8= -0.0974, C9=0.11738, C10= -0.1807, C11=0.0000, C12= -0.6905, C13=0.83269, C14=0.78138 and the sum of the sine components is 0.7814.

[0045] The cosine components multiplied with F(n) of equation a) for the respective cylinders are the following: C1=1, C2= -0.7695, C3= 0.44156, C4= -0.1251, C5= -0.3752, C6= -0.0602, C7=0.07771, C8= -0.0777, C9=0.24374, C10=0.37518, C11= -0.56232, C12=0.15759, C13= 0.19006, C14= -0.6235 and the sum of the cosine components is -0.108. The resulting length of the vector is the square root of (0.7814 x 0.7814 plus -0.108 x -0.108) = 0.789, which is well below the value of 2.5.

[0046] With respect to the value for the 5th order gas forces stipulated in requirement b) the sine components multiplied with F(n) for the respective cylinders are the following: C1=0, C2= -0.8327, C3= -0.3073, C4=0.43964, C5=0.40598, C6=0.21151, C7=0.05408, C8=0.0541, C9=0.26375, C10= -0.406, C11=0.000, C12=0.5537, C13=0.6678, C14= -0.4339, and the sum of the sine components is 0.6707.

[0047] The cosine components multiplied with F(n) of equation b) for the respective cylinders are the following: C1=1, C2=0.19006, C3= -0.6381, C4= -0.3506, C5=0.09266, C6=0.16867, C7= -0.1123, C8= -0.1123, C9=0.0602, C10=0.09266, C11=0.56232, C12= -0.4416, C13=0.53253, C14= -0.901 and the sum of the cosine components is 0.1433. The resulting length of the vector is 0.6858, which is well below the value of 2.0.

[0048] With respect to the value for the 6th order gas forces stipulated in requirement c) the sine components multiplied with F(n) for the respective cylinders are the following: C1=0, C2=0.66777, C3=0.69046, C4=0.24398, C5= -0.3256, C6= -0.1174, C7= -0.1215, C8=0.12151, C9=0.21151, C10= -0.3256, C11=0.0000, C12= -0.3073, C13=0.37058, C14= -0.9749, and the sum of the sine components is 0.1336.

[0049] The cosine components multiplied with F(n) of equation c) for the respective cylinders are the following: C1=1, C2=0.53253, C3= -0.1576, C4= -0.5066, C5=0.25964, C6= -0.2437, C7= -0.0277, C8=0.02773, C9= -0.1687, C10= -0.2596, C11= -0.5623, C12=0.63808, C13=0.76952, C14=0.22252 and the sum of the cosine components is 1.5237. The resulting length of the vector is 1.5295, which is well below the value of 2.1.

[0050] With respect to the value for the 7th order gas forces stipulated in requirement d) the sine components multiplied with F(n) for the respective cylinders are the following: C1=0, C2=0.0000, C3=0.0000, C4=0.0000, C5=0.0000, C6=0.0000, C7=0.0000, C8=0.0000, C9=0.0000, C10=0.0000, C11=0.0000, C12=0.0000, C13=0.0000, C14=0.0000, and the sum of the sine components is 0.00.

[0051] The cosine components multiplied with F(n) of equation d) for the respective cylinders are the following: C1=1, C2= -0.8541, C3=0.7082, C4= -0.5623, C5= -0.4164, C6=0.2705, C7=0.1246, C8=0.12464, C9= -0.2705, C10= -0.4164, C11=0.5623, C12= -0.7082, C13=0.85411, C14=1.0 and the sum of the cosine components is 1.4164. The resulting length of the vector is 1.4164, which is well below the value of 2.2.

[0052] For the calculation of the nick moments relevant to requirements e) and f) values of F(n) are calculated in the following manner: F(n) = F(n-1) + ((distance from the centre line of cylinder C_{n-1} to the centre line of cylinder C_n)/(nominal distance between cylinders)). The nominal distance between cylinders is the horizontal distance between the vertical centre lines of two adjacent cylinders having no chain drive in between the cylinders. When the engine is provided with a chain drive for a camshaft, this chain drive is typically located at the middle of the engine. The nominal distance between cylinders can consequently in the ordinary case be identified as the distance between cylinders in the end area of the engine, such as the distance between cylinders C1 and C2. For the above mentioned engine the following values are found: F(1)=0, F(2)=1, F(3)=2, F(4)=3, F(5)=4, F(6)=5, F(7)=6, F(8)=7.70857, F(9)=8.70857, F(10)=9.70857, F(11)=10.70857, F(12)=11.70857, F(13)=12.70857, and F(14)=13.70857.

[0053] With respect to the value for the 1st order nick moments in requirement e) the sine components multiplied with F(n) for the respective cylinders are the following: C1=0, C2=0.78183, C3= -1.94499, C4=1.30165, C5= -3.1273, C6=2.1694, C7=5.84957, C8= -7.5153, C9=6.8086, C10= -7.5905, C11= 0.0000, C12= -5.0802, C13= -5.514, C14=13.3649 and the sum of the sine components is -0.501.

[0054] The cosine components multiplied with F(n) of equation e) for the respective cylinders are the following: C1=0, C2= -0.6235, C3= -0.445, C4=2.70291, C5= -2.49396, C6= -4.50484, C7= -1.3351, C8=1.71532, C9=5.42971, C10=6.0532, C11= -10.7086, C12= -10.549, C13=11.45, C14=3.0504 and the sum of the cosine components is -0.258. The resulting length of the vector is 0.5639, which is well below the value of 2.5.

[0055] With respect to the value for the 2nd order nick moments in requirement f) the sine components multiplied with F(n) for the respective cylinders are the following: C1=0, C2=-0.9749, C3=0.86777, C4=2.34549, C5=3.8997, C6= -3.90916, C7= -2.6033, C8= -3.3446, C9=8.4902, C10= -9.4652, C11=0.0000, C12=9.15413, C13= -9.936, C14=5.9479, and the sum of the sine components is 0.4721.

[0056] The cosine components multiplied with F(n) of equation f) for the respective cylinders are the following: C1=0, C2= -0.2225, C3= -1.8019, C4=1.87047, C5= -0.89008, C6=3.1174, C7= -5.4058, C8= -6.9452, C9= -1.9378, C10= -2.1604, C11= 10.70857, C12= 7.30017, C13=7.92366, C14= -12.351 and the sum of the cosine components is -0.794. The resulting length of the vector is 0.9241, which is well below the value of 6.0.

[0057] The forces producing the nick moments are illustrated in Fig. 6. When cylinder 14 performs a combustion sequence the upwards directed force on the cylinder cover results in upwards directed forces 36 in the four tie-rods that connect the cylinder portion with the bedplate, and at the same time the main bearing associated with cylinder 14 is subjected to a downwards directed thrust force 37. Similar forces occur at the other cylinders as they fire. These vertically acting forces produce the so-called nick moments that act on the engine and the engine supporting structure in a manner that can introduce vertical vibrations. These vertical vibrations can have negative influences, in particular when the engine is a main propulsion engine in a container ship, because the nick moments will induce hull vibrations of a highly undesired character. The engine according to the present invention has firing sequences that limit the size of the nick moments, and the engine is consequently particularly suitable for use in a container ship which typically has a long hull and requires a main engine producing a very large power in order to propel the ship at the high speed required when transporting cargo of high value. In addition to solving the problems of different filling of the engine cylinders, a problem which is of particular relevance to an engine of high power, the engine according to the present invention solves at the same time one of the major vibration problems pertaining to container ship propulsion.

[0058] The engine according to the present invention is thus particularly suitable for use as a main propulsion engine in a container ship, and especially in a container ship having a capacity of at least 10.000 TEU, such as from 10.200 to 14.000 TEU, one TEU being the equivalent of a single 20' container. TEU is the standard measure for the capacity of a container ship.

[0059] The below Table 1 presents relevant vibration values of some of the other above mentioned firing sequences. The firing sequences are numbered FS 1 etc in accordance with the numbering of the above mentioned sequences. The table states the vector lengths according to each of the requirements a) to f).

Table 1

FS No.	a) G4	b) G5	c) G6	d) G7	e) N1	f) N2
2	0.97	0.67	1.26	1.71	0.364	0.52
5	0.88	0.56	1.31	2	1.148	1.137
9	0.56	0.35	1.42	1.12	0.589	1.499
13	0.97	0.67	1.26	1.71	0.364	0.52
14	0.57	0.72	1.2	2	0.384	1.264
21	0.44	0.74	1.06	1.42	0.702	1.015
27	0.44	0.62	1.87	1.42	1.402	0.762
31	0.87	0.72	1.99	1.42	0.246	1.335
45	0.833	0.735	0.419	0.833	0.724	1.057
46	0.31	0.212	0.867	0.541	0.997	1.468
47	0.371	0.355	0.755	0.249	1.002	1.318
48	0	0.948	0	0.541	1.044	0
49	0.323	0.902	0.402	0.249	1.151	1.227
50	0.401	0.875	0.846	0.833	1.155	0.894
51	0.102	0.628	0.513	0.541	1.413	1.082
52	0.445	0.964	0.247	0.334	1.429	1.357
53	0.682	0.376	0.748	0.833	0.35	0.93
54	0.909	0.976	0.978	0.833	0.429	0.474
55	0.909	0.492	0.978	0.541	0.741	0.474

[0060] It is possible to make modifications to the embodiments described in the above. It is e.g. possible to use another number of turbochargers on the engine, such as two or three turbochargers, and also more than four turbochargers, such as from five to eight turbochargers. The engine frame can be of any suitable shape, and the cylinder sections can be integrated in the frame. The scavenge air receiver - and possibly also the exhaust gas receiver - can have other cross-sectional shapes that the circular shape, such as a polygonal shape or a part-circular shape combined with one or more linear segments. The scavenge air system can include further elements than described, such as water mist collectors. The cylinders need not be numbered with C1 at the forward end of the engine and C14 at the aft end. They can equally well be numbered with C1 at the aft end and C14 at the forward end. As an alternative to being a main engine in a ship, the engine can be utilized as a stationary engine in a power plant.

[0061] It is also possible to set stricter criteria for the requirements than the above mentioned criteria. As examples, with respect to the gas pulsation, requirement a) can be Vgas(4)< 1.2 or Vgas(4)< 0.9. With respect to the gas pulsation, requirement b) can be limited to Vgas(5)< 1.2 or Vgas(5)< 1.0, requirement c) can be limited to Vgas(6)< 1.2 or Vgas (6)< 1.0, and requirement d) can be limited to Vgas(7)< 2.0 or Vgas(7)< 1.5. Requirement e) can be limited to Vnick (1)< 1.3 or Vnick(1)< 1.0, and requirement e) can be limited to Vnick(2)< 1.3 or Vnick(2)< 1.0. These more strict requirements can be applied individually or in combination according to desire. The stricter requirements reduce the number of firing sequences fulfilling the requirements, but at the same time they result in 14 cylinder engines having even more favourable vibration characteristics.

Claims

1. Two-stroke turbocharged internal combustion engine having 14 cylinders in a single row, at least one exhaust gas receiver, at least two turbochargers, and a scavenge air system with at least one elongated scavenge air receiver, each cylinder having a scavenge air inlet connected to the scavenge air receiver and an exhaust passage leading into the at least one exhaust gas receiver, said turbochargers being connected with the exhaust gas receiver on its turbine side and with the scavenge air system on its compressor side, which engine has a firing sequence (n1 - n14) of the engine cylinders C1-C14, **characterized in that** the fourteen cylinders have a firing sequence (n1 - n14) so that at least the following four requirements a) to d) are met

   for the 4th order gas pulsation

$$\text{a) } V_{GAS}(4) = \left| \sum_{n=1}^{n=14} F(n) \cdot (\sin(4(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(4(\omega t + \varphi_n))) \right| < 2.5$$

   for the 5th order gas pulsation

$$\text{b) } V_{GAS}(5) = \left| \sum_{n=1}^{n=14} F(n) \cdot (\sin(5(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(5(\omega t + \varphi_n))) \right| < 2.0$$

   for the 6th order gas pulsation

$$\text{c) } V_{GAS}(6) = \left| \sum_{n=1}^{n=14} F(n) \cdot (\sin(6(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(6(\omega t + \varphi_n))) \right| < 2.1$$

   for the 7th order gas pulsation

$$\text{d) } V_{GAS}(7) = \left| \sum_{n=1}^{n=14} F(n) \cdot (\sin(7(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(7(\omega t + \varphi_n))) \right| < 2.2$$

   where n is the cylinder number, φ_n is the firing angle for cylinder n, F(n) is a weighting function linearly interpolated with respect to the position of the cylinder between F(1) = 1 at cylinder C1 and F(14) = -1 at cylinder C14, and || identifies the length of the vector.

2. Two-stroke turbocharged internal combustion engine according to claim 1, **characterized in that** the fourteen cylinders have a firing sequence (n1 - n14) so that the following requirement e) is also met

$$\text{e) } V_{Nick}(1) = \left| \sum_{n=1}^{n=14} F(n) \cdot ((\sin(\omega t + \varphi_n) + \sqrt{-1} \cdot \cos(\omega t + \varphi_n)) \right| < 2.5$$

   where n is the cylinder number, φ_n is the firing angle for cylinder n, F(n) is a weighting function which is F(1) = 0 at cylinder C1 and F(n) = F(n-1) + ((distance from the centre line of cylinder C_{n-1} to the centre line of cylinder C_n) /(nominal distance between cylinders)), and || identifies the length of the vector.

3. Two-stroke turbocharged internal combustion engine according to claim 1 or 2, **characterized in that** the fourteen cylinders have a firing sequence (n1 - n14) so that the following requirement f) is also met

f) $$V_{Nick}(2) = \left| \sum_{n=1}^{n=14} F(n) \cdot ((\sin(2(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(2(\omega t + \varphi_n))) \right| < 6.0$$

where n is the cylinder number, φ_n is the firing angle for cylinder n, F(n) is a weighting function which is F(1) = 0 at cylinder C1 and F(n) = F(n-1) + ((distance from the centre line of cylinder C_{n-1} to the centre line of cylinder C_n) /(nominal distance between cylinders)), and ‖ identifies the length of the vector.

4. Two-stroke turbocharged internal combustion engine according to claims 1 and 2 and 3, **characterized in that** the fourteen cylinders have a firing sequence (n1 - n14) so that

a) for the 4^{th} order gas pulsation Vgas(4)< 2,
b) for the 5^{th} order gas pulsation Vgas(5)< 2,
c) for the 6^{th} order gas pulsation Vgas(6)< 2,
d) for the 7^{th} order gas pulsation Vgas(7)< 2.2,
e) for the 1^{st} order nick-moments Vnick(1)< 2,
f) for the 2^{nd} order nick-moments Vnick(2)< 3.

5. Two-stroke turbocharged internal combustion engine according to claim 4, **characterized in that** the fourteen cylinders have a firing sequence (n1 - n14) so that

a) for the 4^{th} order gas pulsation Vgas(4)< 1,
b) for the 5^{th} order gas pulsation Vgas(5)< 2,
c) for the 6^{th} order gas pulsation Vgas(6)< 2,
d) for the 7^{th} order gas pulsation Vgas(7)< 2.2,
e) for the 1^{st} order nick-moments Vnick(1)< 1.5,
f) for the 2^{nd} order nick-moments Vnick(2)< 1.5.

6. Two-stroke constant-pressure turbocharged internal combustion engine according to any one of claims 1 to 5, **characterized in that** the firing sequence is even in the sense that the turning angle of the crankshaft between the firing of two consecutive cylinders is 360°/14.

7. Two-stroke turbocharged internal combustion engine according to any one of claims 1 to 5, **characterized in that** the firing sequence is uneven in the sense that the turning angle of the crankshaft between the firing of at least two pair of consecutively firing cylinders is different from 360°/14.

8. Two-stroke constant-pressure turbocharged internal combustion engine according to any one of claims 1 to 7, **characterized in that** the engine is a main propulsion engine in a container ship, preferably a container ship having a capacity of more than 10.000 TEU.

9. Two-stroke turbocharged internal combustion engine according to claim 8, **characterized in that** the engine has a maximum power per cylinder of at least 5000 kW.

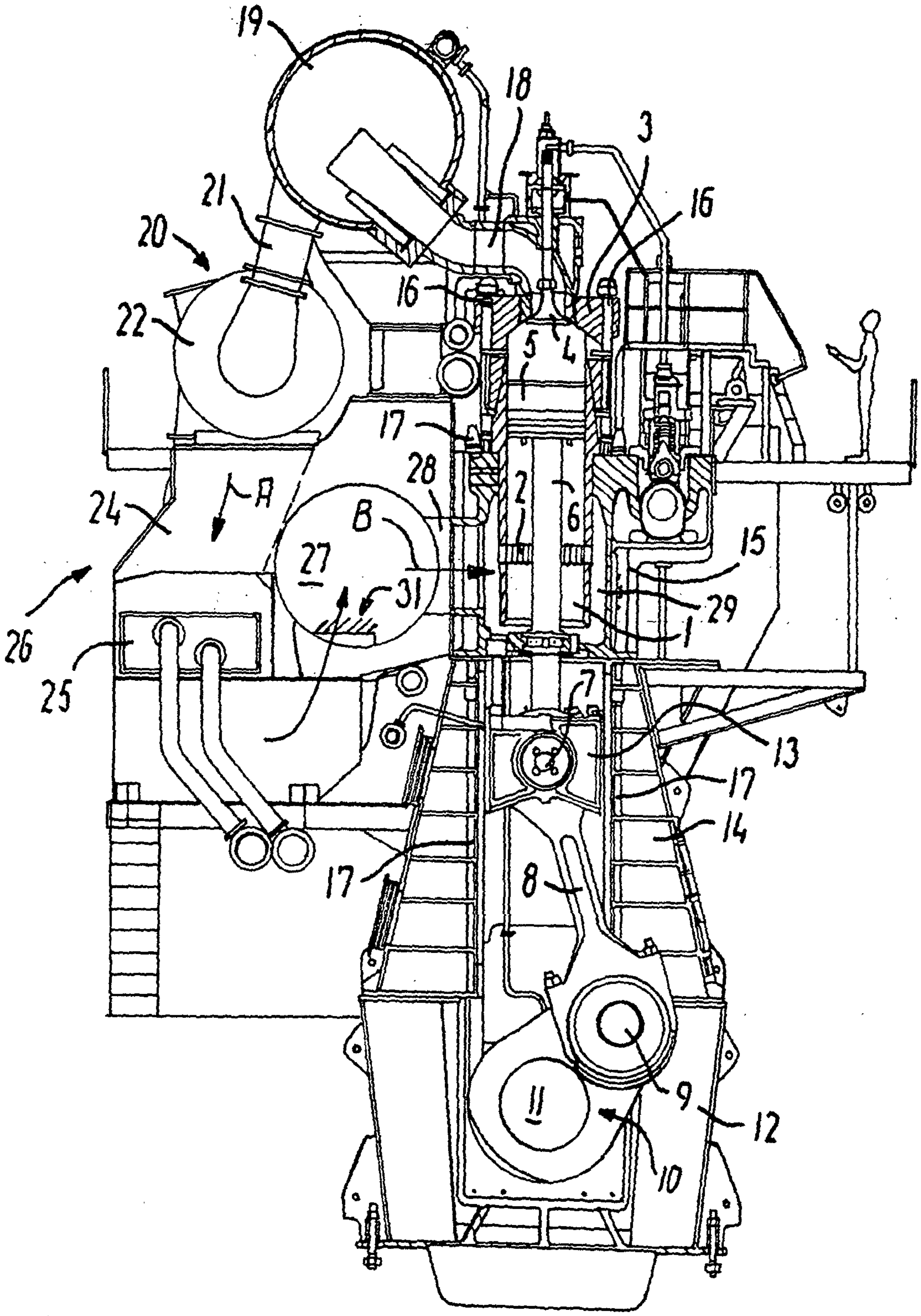
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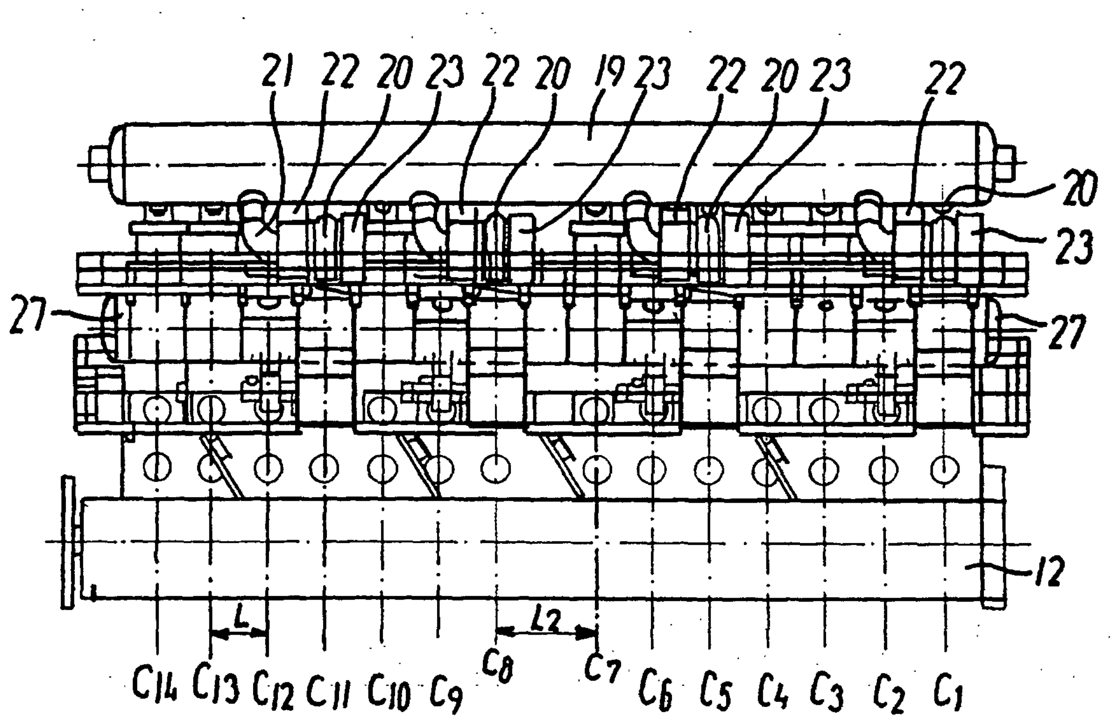
FIG.1


21 22 20 23 22 20 19 23 22 20 23 22
20
23
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L
L2
C14 C13 C12 C11 C10 C9 C8 C7 C6 C5 C4 C3 C2 C1

FIG.2

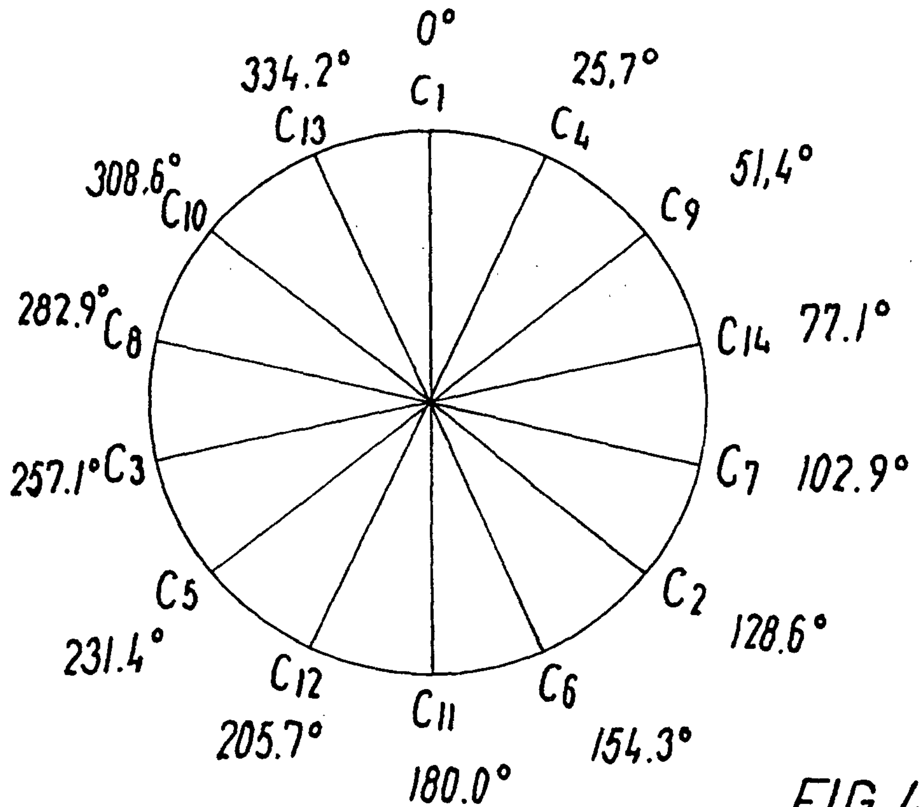
0°
C1
25,7°
C4
51,4°
C9
77.1°
C14
102.9°
C7
128.6°
C2
154.3°
C6
180.0°
C11
205.7°
C12
231.4°
C5
257.1°
C3
282.9°
C8
308.6°
C10
334.2°
C13

FIG.4

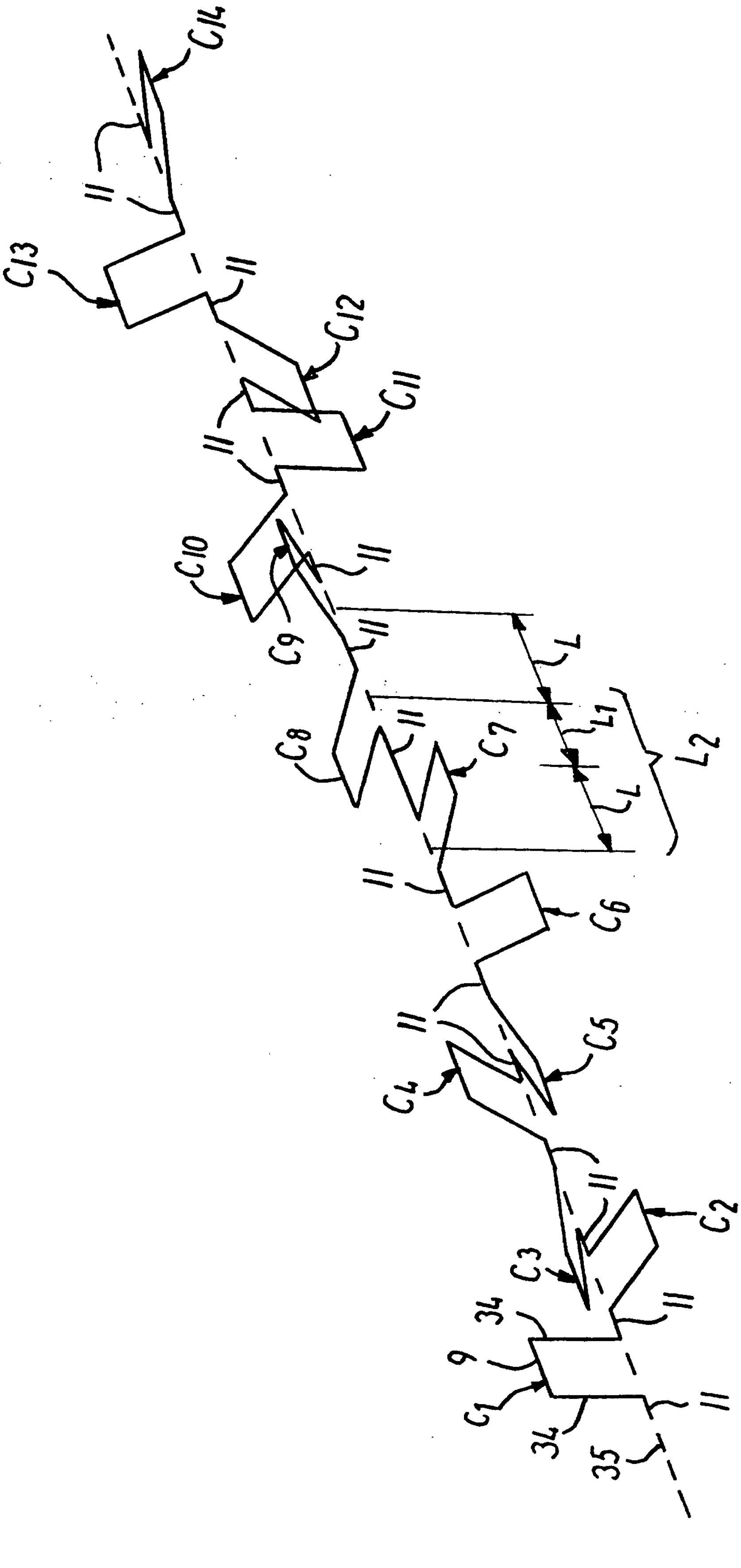

FIG. 3

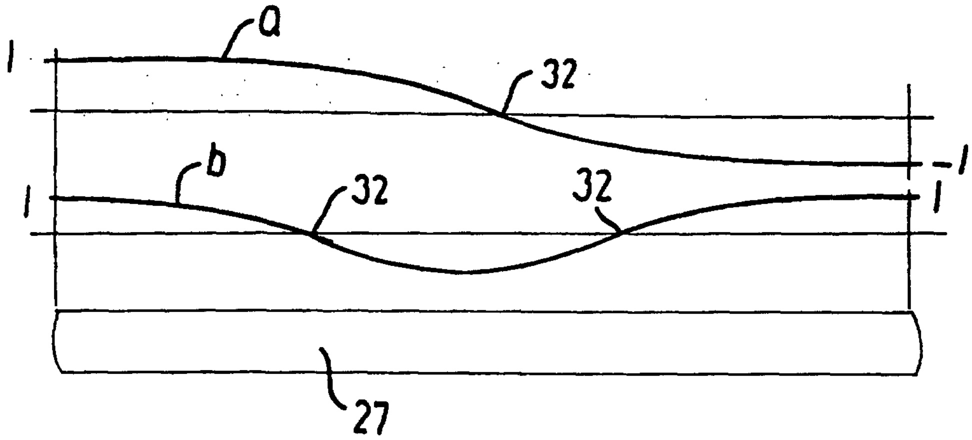

FIG.5

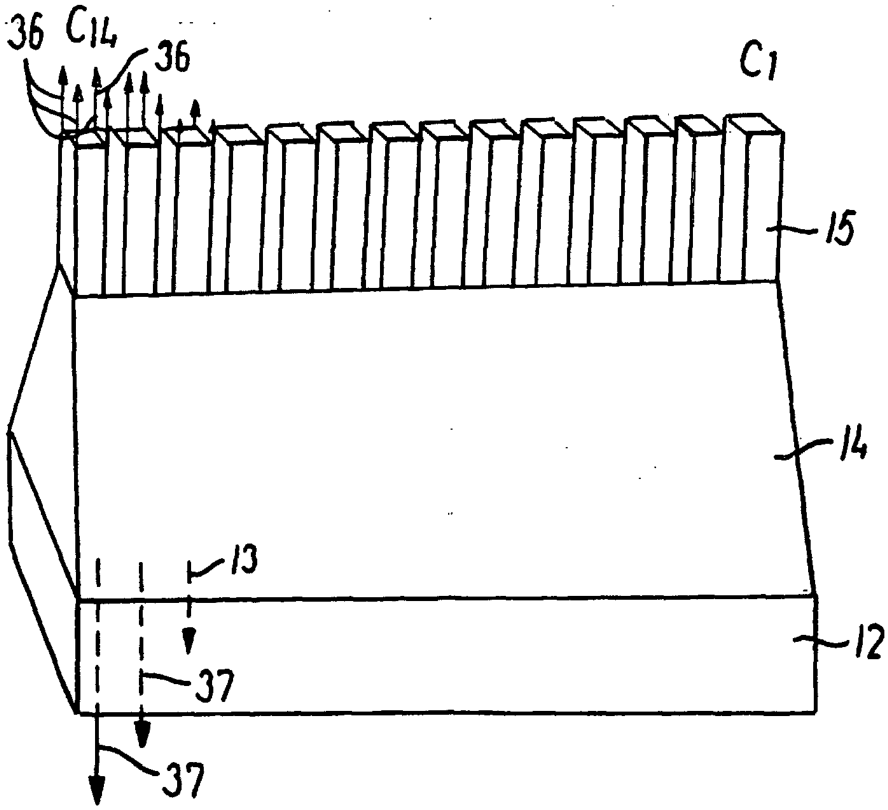

FIG.6

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 04 07 6262

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	PROF V A VANSCHEIDT: "DIESELS, REFERENCE MANUAL passage" DIESELS, REFERENCE MANUAL, XX, XX, 1964, pages 157-166, XP002214395 * the whole document * -----	1-9	F02B75/00 F02B75/20
A	GB 322 161 A (VIGGO AXEL KJAER) 26 November 1929 (1929-11-26) * figures 1-11 * * claims 1-11 * -----	1-9	
A	EP 1 367 238 A (WAERTSILAE SCHWEIZ AG) 3 December 2003 (2003-12-03) * the whole document * -----	1-9	
A	"MAN B&W AND SULZER BREAK THE MOULD" SHIPPING WORLD AND SHIPBUILDER, BENN PUBLICATIONS LTD. LONDON, GB, vol. 202, no. 4172, April 2001 (2001-04), page 46, XP001112367 ISSN: 0037-3931 * the whole document * -----	1-9	TECHNICAL FIELDS SEARCHED (Int.Cl.7) F02B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	11 June 2004	Wassenaar, G

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11-06-2004

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