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(54) **Two-stroke constant-pressure turbocharged internal combustion engine having 13 cylinders in a single row**

(57) A two-stroke constant-pressure turbocharged internal combustion engine has 13 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-n13) of the engine cylinders (C1-C13), so that at least the following three requirements a) to c) are met:

for the 4th order gas pulsation

$$\text{a) } V_{GAS}(4) = \left| \sum_{n=1}^{n=13} F(n) \cdot (\sin(4(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(4(\omega t + \varphi_n))) \right| < 1.8$$

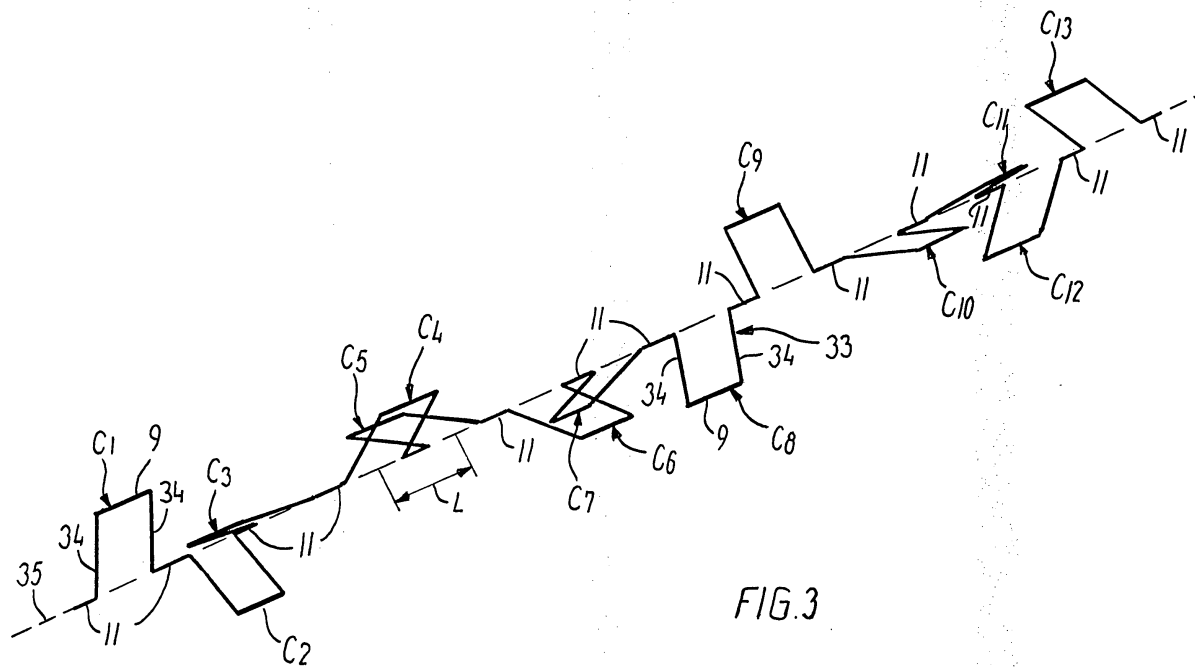
for the 5th order gas pulsation

$$\text{b) } V_{GAS}(5) = \left| \sum_{n=1}^{n=13} F(n) \cdot (\sin(5(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(5(\omega t + \varphi_n))) \right| < 1.8$$

for the 6th order gas pulsation

$$\text{c) } V_{GAS}(6) = \left| \sum_{n=1}^{n=13} F(n) \cdot (\sin(6(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(6(\omega t + \varphi_n))) \right| < 1.8$$

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(13) = -1 at cylinder C13, and || identifies the length of the vector.



Description

[0001] The present invention relates to a two-stroke constant-pressure turbocharged internal combustion engine having 13 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 - n13) of the engine cylinders C1-C13.

[0002] Constant-pressure turbocharging of an internal combustion engine 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 13 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 13 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 thirteen cylinders have a firing sequence (n1 - n13) so that at least the following three requirements a) to c) are met

for the 4th order gas pulsation

$$a) V_{GAS}(4) = \left| \sum_{n=1}^{n=13} F(n) \cdot (\sin(4(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(4(\omega t + \varphi_n))) \right| < 1.8$$

for the 5th order gas pulsation

$$b) V_{GAS}(5) = \left| \sum_{n=1}^{n=13} F(n) \cdot (\sin(5(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(5(\omega t + \varphi_n))) \right| < 1.8$$

for the 6th order gas pulsation

$$c) V_{GAS}(6) = \left| \sum_{n=1}^{n=13} F(n) \cdot (\sin(6(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(6(\omega t + \varphi_n))) \right| < 1.8$$

where n is the cylinder number, φ_n is the firing angle for cylinder n, F(n) is a weighting function linearly interpolated between F(1) = 1 at cylinder C1 and F(13) = -1 at cylinder C13, 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 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 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 thirteen cylinders have a firing sequence (n1 - n13) so that the following requirement d) is also met

$$d) \quad V_{Nick}(1) = \left| \sum_{n=1}^{n=13} F(n) \cdot ((\sin(\omega t + \varphi_n) + \sqrt{-1} \cdot \cos(\omega t + \varphi_n))) \right| < 2.5$$

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 no chain drive between the cylinders, typically the distance between the centre lines of cylinders C1 and C2.

[0010] A long in-line engine as a 13 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 c) are further enhanced by also making requirement d) be fulfilled. Requirement d) 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 thirteen cylinders have a firing sequence (n1 - n13) so that the following requirement e) is also met

$$e) \quad V_{Nick}(2) = \left| \sum_{n=1}^{n=13} F(n) \cdot (\sin(2(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(2(\omega t + \varphi_n))) \right| < 6.0$$

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 thirteen cylinders with a firing sequence (n1 - n13) so that both the above mentioned requirements d) and e) are fulfilled, and this minimizes the influence of nick moments on vertical hull vibration.

[0012] 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°/13. 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°/13.

[0013] Examples of embodiments of the present invention are described in more detail in the following with reference to the highly schematical drawings, on which

Fig. 1 is a sectional view of a two-stroke engine with 13 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.

[0014] In Fig. 1 is seen the cross-section through a large two-stroke constant-pressure turbocharged internal combustion engine of the crosshead type, having 13 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, or of the make Mitsubishi Heavy Industries. The cylinders can have a bore in the range of e.g. 60 to 120 cm, preferably from 80 to 120 cm. The engine can e.g. have a power in the range of 3000 to 8000 kW per cylinder, preferably from 4000 to 7000 kW per cylinder,

and suitably at least 5000 kW per cylinder. Each cylinder C1-C13 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.

[0015] 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.

[0016] 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.

[0017] 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.

[0018] 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.

[0019] 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.

[0020] 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.

[0021] 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.

[0022] The inlet air is called both scavenge air and charging air. The inlet air is one and the same. However, for 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 with the scavenge air ports 2.

[0023] 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.

[0024] 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.

[0025] 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 counter-phase 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.

[0026] 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.

[0027] It is of course possible to divide the scavenge air receiver into several receiver sections located one after the

EP 1 548 251 A1

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.

[0028] By choosing the firing sequence in accordance with the above mentioned requirements a) to c) 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.

[0029] Examples of firing sequences fulfilling the requirements can be given as follows:

No.	Firing sequence for cylinders C1 to C13												
1	1	4	11	10	6	2	8	12	7	3	5	13	9
2	1	5	13	9	4	2	11	10	6	3	7	12	8
3	1	6	10	11	4	2	9	12	5	3	7	13	8
4	1	6	10	11	4	2	9	13	5	3	7	12	8
5	1	6	11	10	4	2	9	13	5	3	7	12	8
6	1	6	12	9	2	5	10	11	4	3	8	13	7
7	1	6	13	8	2	5	11	10	4	3	9	12	7
8	1	7	12	9	2	4	11	10	5	3	8	13	6
9	1	7	12	9	2	5	11	10	4	3	8	13	6
10	1	7	13	8	2	5	10	11	4	3	9	12	6
11	1	7	13	8	2	5	12	9	4	3	10	11	6
12	1	8	13	6	2	7	11	9	3	4	10	12	5
13	1	8	13	7	2	5	11	10	4	3	9	12	6
14	1	8	13	7	2	5	12	9	3	4	10	11	6
15	1	8	13	7	2	5	12	9	3	4	11	10	6
16	1	8	13	7	2	5	12	9	4	3	11	10	6
17	1	8	13	7	2	5	12	10	3	4	9	11	6
18	1	8	13	7	2	6	10	11	3	4	9	12	5
19	1	8	13	7	2	6	11	9	3	4	10	12	5
20	1	8	13	7	2	6	11	10	4	3	9	12	5
21	1	8	13	7	2	6	12	9	3	4	10	11	5
22	1	9	11	7	2	6	13	8	3	4	10	12	5
23	1	9	11	7	2	6	13	8	4	3	10	12	5
24	1	9	12	7	2	5	13	8	3	4	10	11	6
25	1	9	12	7	2	5	13	8	3	4	11	10	6
26	1	9	12	7	2	5	13	8	4	3	10	11	6
27	1	9	12	7	2	6	11	10	3	4	8	13	5
28	1	9	12	7	2	6	11	10	3	5	8	13	4
29	1	9	12	7	2	6	13	8	3	4	10	11	5
30	1	9	12	7	2	6	13	8	3	4	11	10	5
31	1	9	13	5	2	7	12	8	3	4	11	10	6
32	1	9	13	6	2	7	11	8	4	3	12	10	5
33	1	9	13	6	2	7	12	8	3	4	10	11	5
34	1	9	13	6	2	7	12	8	3	4	11	10	5
35	1	9	13	6	2	7	12	8	3	5	10	11	4
36	1	9	13	6	2	7	12	8	4	3	11	10	5
37	1	10	13	5	2	7	12,	8	3	4	11	9	6.

[0030] In the mentioned firing sequence No. 1 the cylinders C1 to C13 fire in the sequence 1 4 11 10 6 2 8 12 7 3 5 13 9. The firing sequence is implemented in the engine by 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 even firing sequence, viz. a firing sequence with a regular (even) angular interval of $360^\circ/13$ 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.

[0031] The distance 1 between the cylinders is constant through out the crankshaft illustrated in Fig. 3. It is also possible to have the constant distance l between most of the cylinders, as illustrated in Fig. 2, except between cylinders C7 and C8 where the distance is $l_2 = l + l_1$, that is the normal distance l between cylinders plus an additional length l_1 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 13 cylinder engine of the relevant size can have a weight well above 250 t. The distance l_2 between the cylinders located at the joint is larger than the distance l between the other cylinders. It is also possible to locate the crankshaft joint between other cylinders, such as cylinders C6 and C7.

[0032] 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.

[0033] 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 $360^\circ/13$. 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.

[0034] The calculation of whether a particular firing sequence fulfils the individual requirements a) to c) and the further requirements d) and/or e) is typically performed electronically by a computer program such as PROFIR developed by MAN B&W Diesel or by 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.

[0035] The calculations are in the following exemplified with respect to the 13 cylinder engine illustrated in Fig. 2. The engine is of the make MAN B&W Diesel and the type MC, more specifically 13K98MC, having a cylinder bore of 0.98 m and a nominal cylinder distance of $l = 1.75$ m. The total length between the vertical centre lines of cylinders C1 and C13 is 22.3 m, and a chain drive is located between cylinders C7 and C8. The chain drive occupies a distance of 1.3 m so that the resulting distance between cylinders C7 and C8 is $l_2 = 3.05$ m. With the above mentioned firing sequence No. 1, 1 4 11 10 6 2 8 12 7 3 5 13 9, the following values are calculated.

[0036] Firing angles for cylinders C1 to C13: 0° , 138.5° , 249.2° , 27.7° , 276.9° , 110.8° , 221.5° , 166.2° , 332.3° , 83.1° , 55.4° , 193.8° , and 304.6° .

[0037] 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 $F(13) = -1$ at cylinder C13: $F(1) = 1$, $F(2) = 0.84305$, $F(3) = 0.6861$, $F(4) = 0.52915$, $F(5) = 0.3722$, $F(6) = 0.2152$, $F(7) = 0.0583$, $F(8) = -0.2152$, $F(9) = -0.3722$, $F(10) = -0.5291$, $F(11) = -0.6861$, $F(12) = -0.843$, and $F(13) = -1$. The position of the cylinder is calculated as the distance of the cylinder C_n from the cylinder C1 in the longitudinal direction of the engine divided by the total distance between the centre lines of cylinders C1 and C13. $F(n)$ is consequently equal to $1 - 2 \times (\text{distance of cylinder } C_n \text{ from cylinder C1}) / (\text{total distance from cylinder C1 to cylinder C13})$.

[0038] With respect to the value of ωt in the vector summation of equations a) to e) the length of the vector can be calculated with the value $t=0$, as the length of the resulting vector is independent of time.

[0039] 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= -0.2018, C3= -0.6811, C4= 0.49476, C5=0.17297, C6=0.21368, C7=0.01395, C8=0.17714, C9=0.34801, C10=0.24591, C11=0.45497, C12= -0.6938, C13= -0.6631, and the sum of the sine components is -0.118.

[0040] The cosine components multiplied with $F(n)$ of equation a) for the respective cylinders are the following: C1=1, C2= -0.8186, C3= 0.0827, C4= -0.1876, C5=0.32956, C6=0.02595, C7= -0.0566, C8= -0.1223, C9=0.13198, C10= -0.4685, C11=0.51355, C12= -0.4789, C13= 0.74851 and the sum of the cosine components is 0.700. The resulting length of the vector is the square root of $(-0.118 \times -0.118 \text{ plus } 0.7 \times 0.7) = 0.71$, which is well below the value of 1.8.

[0041] 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= -0.3918, C3=0.16419, C4=0.35089, C5= -0.3063, C6= -0.0515, C7=0.02709, C8= -0.2013, C9=0.24681, C10= -0.4355, C11=0.6811, C12=0.78826, C13= -0.9927, and the sum of the sine components is -0.12.

[0042] The cosine components multiplied with $F(n)$ of equation b) for the respective cylinders are the following: C1=1, C2=0.74648, C3= -0.6662, C4= -0.3961, C5=0.21143, C6= -0.209, C7=0.05162, C8=0.07633, C9=0.27859, C10=

-0.3006, C11= -0.0827, C12=0.29895, C13= -0.1205 and the sum of the cosine components is 0.89. The resulting length of the vector is 0.89, which is well below the value of 1.8.

[0043] 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=0.78826, C3=0.56465, C4=0.12663, C5= -0.2468, C6= -0.1771, C7= -0.0545, C8=0.21368, C9=0.08907, C10= -0.3509, C11=0.31885, C12= -0.8369, C13= -0.4647, and the sum of the sine components is -0.0298.

[0044] The cosine components multiplied with F(n) of equation c) for the respective cylinders are the following: C1=1, C2= -0.2989, C3= 0.38975, C4= -0.5138, C5= -0.2786, C6=0.12227, C7= -0.0207, C8= -0.0259, C9=0.36138, C10=0.39607, C11= -0.6075, C12= -0.1016, C13= -0.8855 and the sum of the cosine components is -0.46. The resulting length of the vector is 0.46, which is well below the value of 1.8.

[0045] For the calculation of the nick moments relevant to requirements d) and e) values of F(n) are calculated in the following manner: $F(n) = F(n-1) + ((\text{distance from the centre line of cylinder } C_{n-1} \text{ to the centre line of cylinder } C_n) / (\text{nominal distance between cylinders}))$. 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)=7.74286, F(9)=8.74286, F(10)=9.74286, F(11)=10.7429, F(12)=11.7429, and F(13)=12.7429.

[0046] With respect to the value for the 1st order nick moments in requirement d) the sine components multiplied with F(n) for the respective cylinders are the following: C1=0, C2=0.66312, C3= -1.87, C4=1.39417, C5= -3.9708, C6=4.67508, C7= -3.9787, C8=1.85299, C9= -4.063, C10=9.67182, C11=8.8412, C12= -2.8102, C13= -10.487, and the sum of the sine components is -0.08.

[0047] The cosine components multiplied with F(n) of equation d) for the respective cylinders are the following: C1=0, C2= -0.7485, C3= -0.7092, C4=2.65637, C5=0.48215, C6= -1.773, C7= -4.4911, C8= -7.5179, C9=7.74142, C10=1.17437, C11=6.10264, C12= -11.402, C13=7.23877 and the sum of the cosine components is -1.25. The resulting length of the vector is 1.245, which is well below the value of 2.5.

[0048] With respect to the value for the 2nd order nick moments in requirement e) the sine components multiplied with F(n) for the respective cylinders are the following: C1=0, C2=-0.9927, C3=1.32625, C4=2.46895, C5= -0.9573, C6= -3.3156, C7=5.95625, C8= -3.5983, C9= -7.1952, C10=2.33162, C11=10.0447, C12=5.45718, C13= -11.915, and the sum of the sine components is -0.39.

[0049] The cosine components multiplied with F(n) of equation e) for the respective cylinders are the following: C1=0, C2=0.12054, C3= -1.497, C4=1.70419, C5= -3.8838, C6= -3.7426, C7=0.72322, C8=6.85596, C9=4.96651, C10= -9.4597, C11= -3.8095, C12= 10.3978, C13= -4.5187 and the sum of the cosine components is -2.14. The resulting length of the vector is 2.178, which is well below the value of 6.0.

[0050] The forces producing the nick moments are illustrated in Fig. 6. When cylinder 13 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 13 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. 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 10.001 to 11.900 TEU or from 12.001 to 14.000 TEU or from more than 13.000 TEU, one TEU being the equivalent of a single 20' container. TEU is the standard measure for the capacity of a container ship.

[0051] 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 e).

Table 1

FS No.	a) G4	b) G5	c) G6	d) N1	e) N2
1	0.71	0.9	0.46	1.248	2.178
3	0.26	0.95	0.56	1.049	2.004
7	0.63	0.28	0.11	0.869	1.936
12	0.89	0.35	0.19	0.917	1.303
17	0.42	0.73	0.09	0.392	2.316
24	0.39	0.81	0.68	1.154	0.438
25	0.35	0.64	0.98	0.894	0.856
29	0.39	0.63	0.48	0.864	0.046
37	0.73	0.87	0.93	0.894	2.259

[0052] It is possible within the scope of the patent claims 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. 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 than the circular shape. 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 C13 at the aft end. They can equally well be numbered with C1 at the aft end and C13 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.

[0053] It is also possible to set stricter criteria for the requirements than the above mentioned criteria. With respect to the gas pulsation, requirement a) can be $V_{gas}(4) < 1.2$ or $V_{gas}(4) < 1.0$. With respect to the gas pulsation, requirement b) can be limited to $V_{gas}(5) < 1.2$ or $V_{gas}(5) < 1.0$, and with respect to the gas pulsation, requirement c) can be limited to $V_{gas}(6) < 1.2$ or $V_{gas}(6) < 1.0$. Requirement d) can be limited to $V_{nick}(1) < 1.5$ or $V_{nick}(1) < 1.3$, and requirement e) can be limited to $V_{nick}(2) < 3.0$ or $V_{nick}(2) < 2.5$. 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 13 cylinder engines having even more favourable vibration characteristics.

Claims

1. Two-stroke constant-pressure turbocharged internal combustion engine having 13 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 - n13) of the engine cylinders C1-C13, **characterized in that** the thirteen cylinders have a firing sequence (n1 - n13) so that at least the following three requirements a) to c) are met for the 4th order gas pulsation

$$a) V_{GAS}(4) = \left| \sum_{n=1}^{n=13} F(n) \cdot (\sin(4(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(4(\omega t + \varphi_n))) \right| < 1.8$$

for the 5th order gas pulsation

$$b) V_{GAS}(5) = \left| \sum_{n=1}^{n=13} F(n) \cdot (\sin(5(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(5(\omega t + \varphi_n))) \right| < 1.8$$

for the 6th order gas pulsation

$$c) \quad V_{GAS}(6) = \left| \sum_{n=1}^{n=13} F(n) \cdot (\sin(6(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(6(\omega t + \varphi_n))) \right| < 1.8$$

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(13) = -1 at cylinder C13, and || identifies the length of the vector.

2. Two-stroke constant-pressure turbocharged internal combustion engine according to claim 1, **characterized in that** the thirteen cylinders have a firing sequence (n1 - n13) so that the following requirement d) is also met

$$d) \quad V_{Nick}(1) = \left| \sum_{n=1}^{n=13} F(n) \cdot ((\sin(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(\omega t + \varphi_n)) \right| < 2.5$$

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 constant-pressure turbocharged internal combustion engine according to claim 1 or 2, **characterized in that** the thirteen cylinders have a firing sequence (n1 - n13) so that the following requirement e) is also met

$$e) \quad V_{Nick}(2) = \left| \sum_{n=1}^{n=13} F(n) \cdot ((\sin(2(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(2(\omega t + \varphi_n))) \right| < 6.0$$

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 constant-pressure turbocharged internal combustion engine according to any one of claims 1 to 3, **characterized in that** the firing sequence is selected from the group consisting of the following firing sequences No. 1 to No. 37:

No.	Firing sequence for cylinders C1 to C13												
1	1	4	11	10	6	2	8	12	7	3	5	13	9
2	1	5	13	9	4	2	11	10	6	3	7	12	8
3	1	6	10	11	4	2	9	12	5	3	7	13	8
4	1	6	10	11	4	2	9	13	5	3	7	12	8
5	1	6	11	10	4	2	9	13	5	3	7	12	8
6	1	6	12	9	2	5	10	11	4	3	8	13	7
7	1	6	13	8	2	5	11	10	4	3	9	12	7
8	1	7	12	9	2	4	11	10	5	3	8	13	6
9	1	7	12	9	2	5	11	10	4	3	8	13	6
10	1	7	13	8	2	5	10	11	4	3	9	12	6
11	1	7	13	8	2	5	12	9	4	3	10	11	6
12	1	8	13	6	2	7	11	9	3	4	10	12	5
13	1	8	13	7	2	5	11	10	4	3	9	12	6
14	1	8	13	7	2	5	12	9	3	4	10	11	6
15	1	8	13	7	2	5	12	9	3	4	11	10	6

(continued)

No.	Firing sequence for cylinders C1 to C13												
16	1	8	13	7	2	5	12	9	4	3	11	10	6
17	1	8	13	7	2	5	12	10	3	4	9	11	6
18	1	8	13	7	2	6	10	11	3	4	9	12	5
19	1	8	13	7	2	6	11	9	3	4	10	12	5
20	1	8	13	7	2	6	11	10	4	3	9	12	5
21	1	8	13	7	2	6	12	9	3	4	10	11	5
22	1	9	11	7	2	6	13	8	3	4	10	12	5
23	1	9	11	7	2	6	13	8	4	3	10	12	5
24	1	9	12	7	2	5	13	8	3	4	10	11	6
25	1	9	12	7	2	5	13	8	3	4	11	10	6
26	1	9	12	7	2	5	13	8	4	3	10	11	6
27	1	9	12	7	2	6	11	10	3	4	8	13	5
28	1	9	12	7	2	6	11	10	3	5	8	13	4
29	1	9	12	7	2	6	13	8	3	4	10	11	5
30	1	9	12	7	2	6	13	8	3	4	11	10	5
31	1	9	13	5	2	7	12	8	3	4	11	10	6
32	1	9	13	6	2	7	11	8	4	3	12	10	5
33	1	9	13	6	2	7	12	8	3	4	10	11	5
34	1	9	13	6	2	7	12	8	3	4	11	10	5
35	1	9	13	6	2	7	12	8	3	5	10	11	4
36	1	9	13	6	2	7	12	8	4	3	11	10	5
37	1	10	13	5	2	7	12	8	3	4	11	9	6.

5. Two-stroke constant-pressure turbocharged internal combustion engine according to any one of claims 1 to 4, **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 $360^\circ/13$.
6. Two-stroke constant-pressure turbocharged internal combustion engine according to any one of claims 1 to 4, **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 $360^\circ/13$.
7. Two-stroke constant-pressure turbocharged internal combustion engine according to any one of claims 1 to 6, **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.
8. Two-stroke turbocharged internal combustion engine according to any one of claims 1 to 7, **characterized in that** the engine has a maximum power per cylinder of at least 5000 kW.

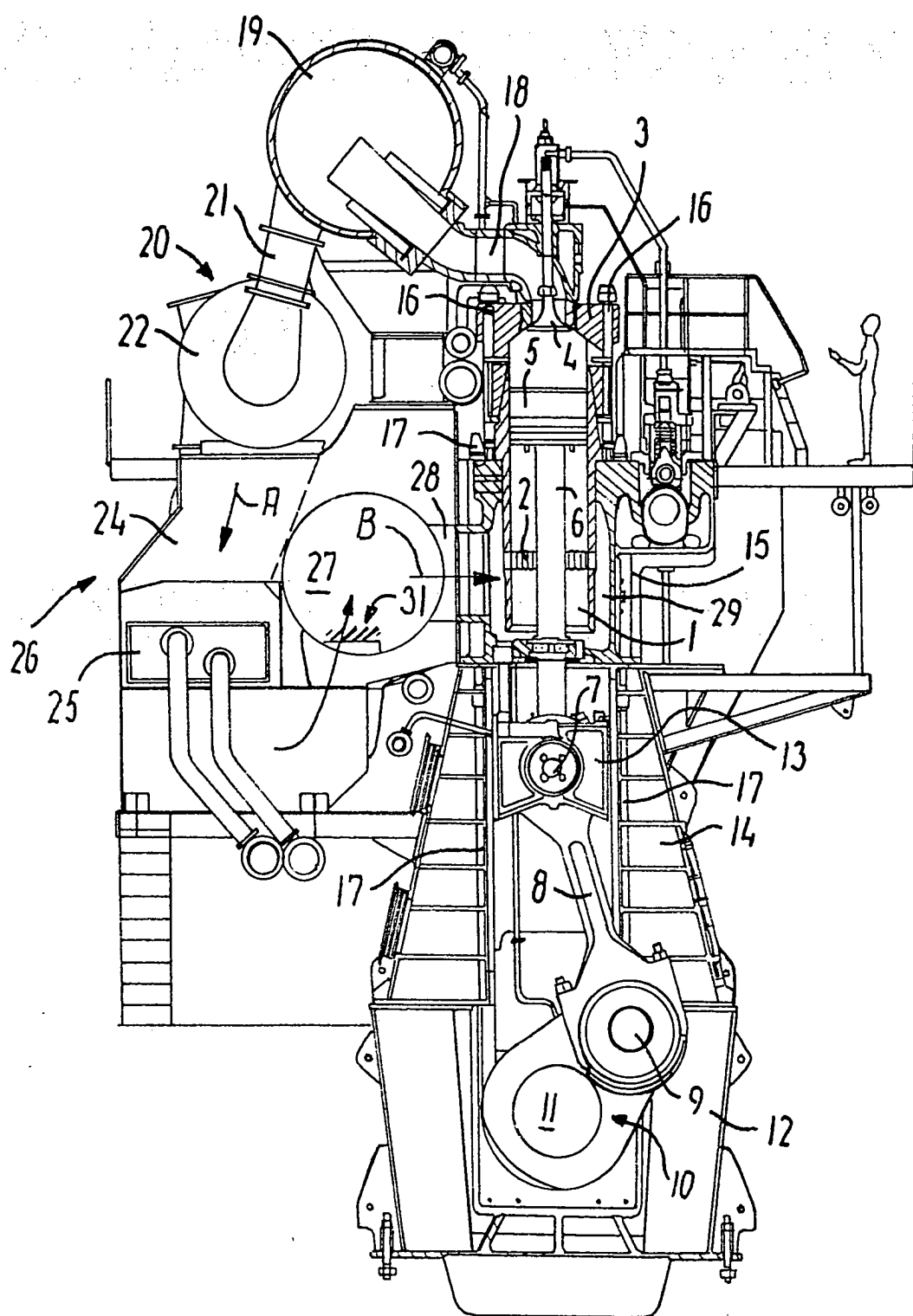


FIG. 1

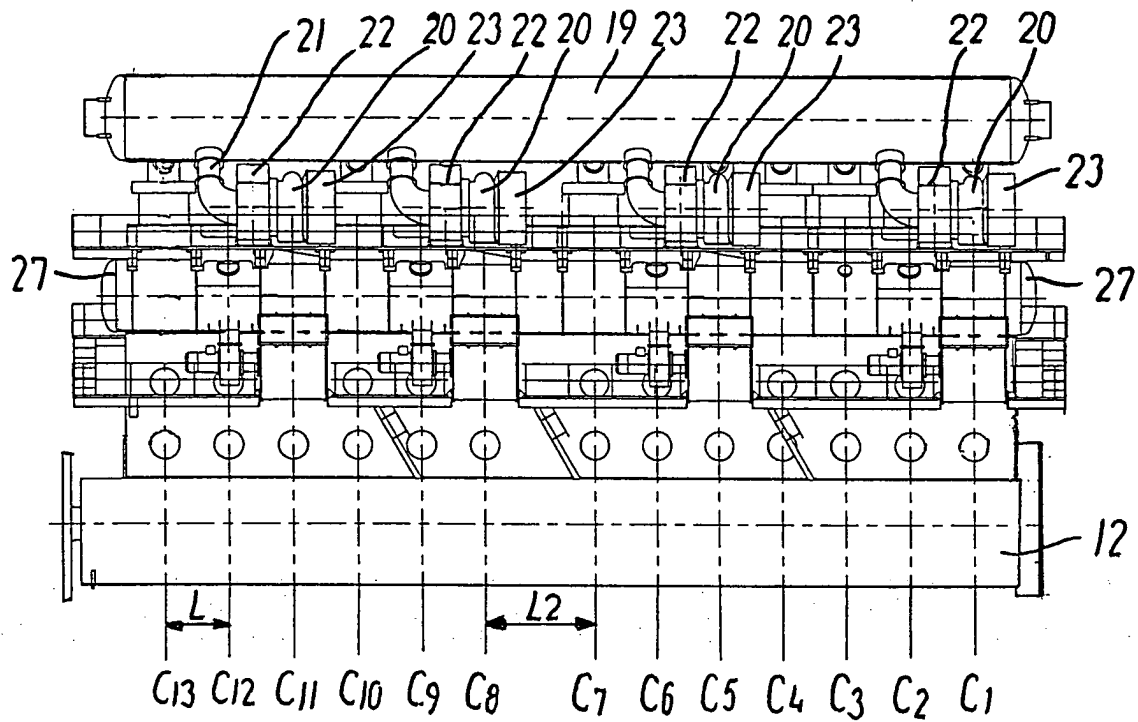


FIG. 2

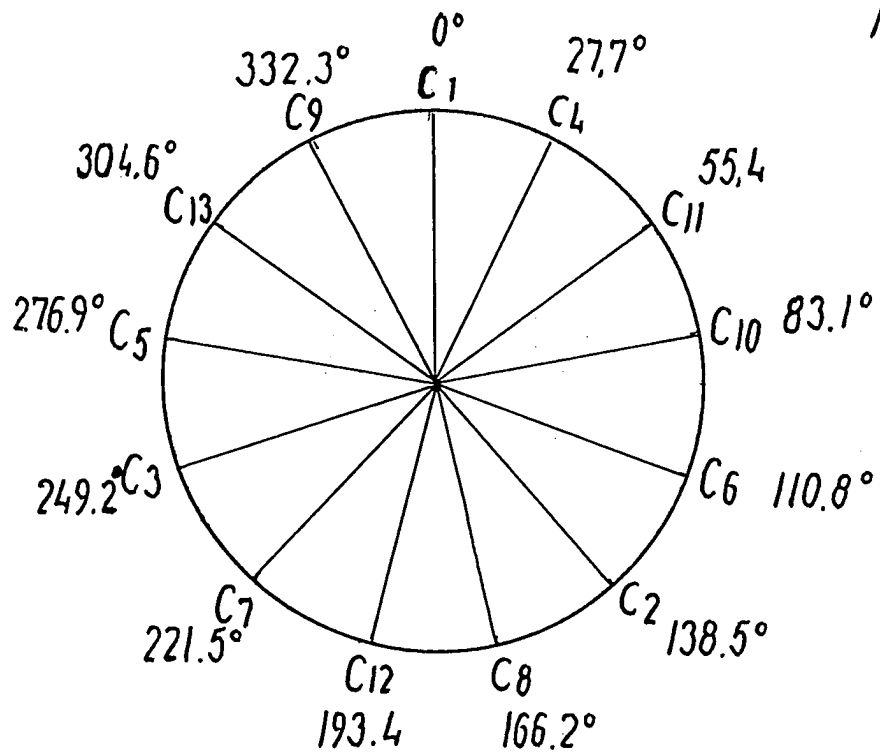
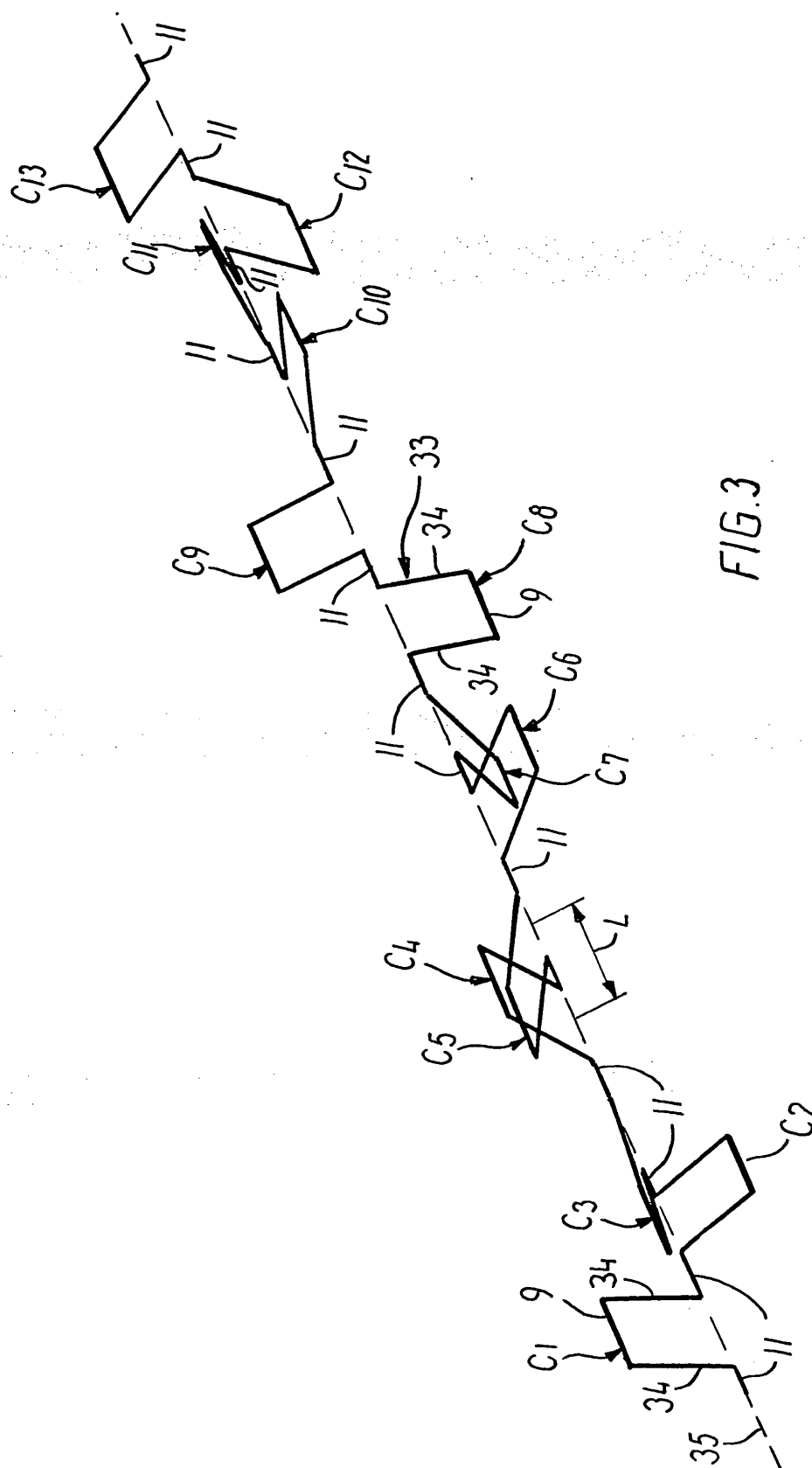


FIG. 4



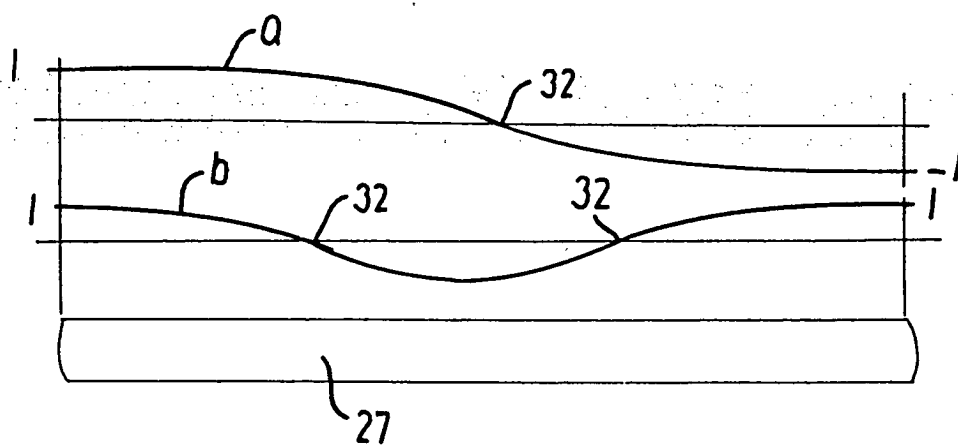


FIG. 5

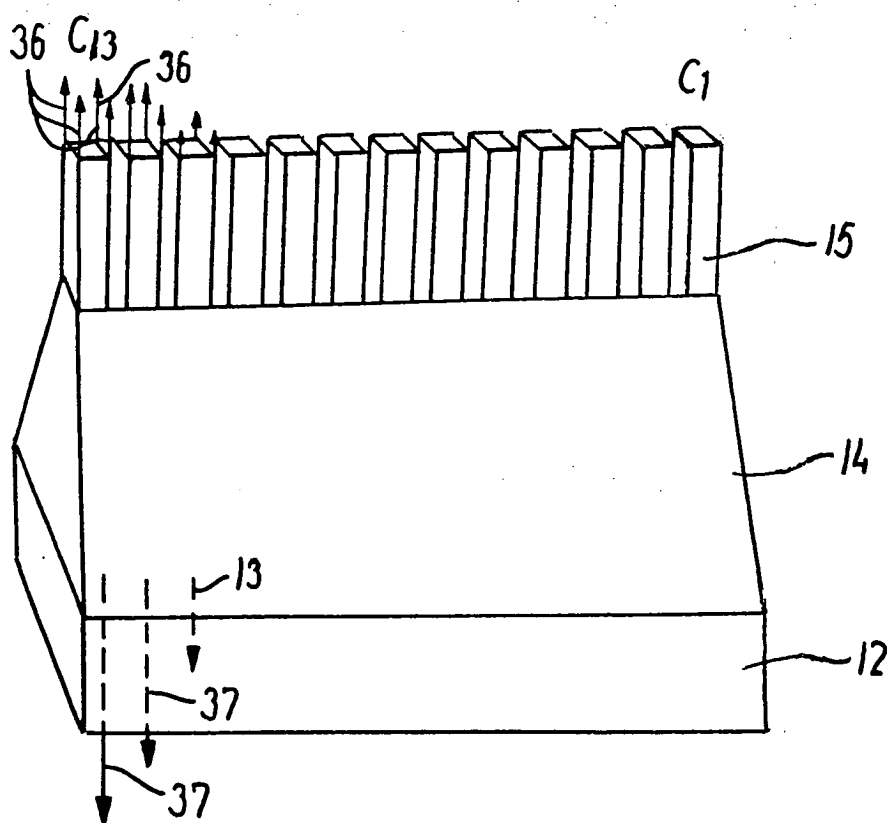


FIG. 6



European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 04 38 8090

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	EP 0 713 000 A (NEW SULZER DIESEL AG; WAERTSILAE NSD SCHWEIZ AG) 22 May 1996 (1996-05-22) * column 2, line 1 - column 3, line 20; figures 1a-1p *	1	F02B75/20
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	
A	----- US 3 748 850 A (VON HOEVEL E,US ET AL) 31 July 1973 (1973-07-31) * column 2, line 40 - column 4, line 10; figures 1-5 *	1	
A	----- EP 1 333 192 A (MITSUBISHI HEAVY INDUSTRIES, LTD) 6 August 2003 (2003-08-06) * tables 1-9 *	1	TECHNICAL FIELDS SEARCHED (Int.Cl.7)
A	----- GB 322 161 A (VIGGO AXEL KJAER) 26 November 1929 (1929-11-26) * page 4, line 60 - page 6, line 34; figures 1-7 *	1	F02B
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 9 March 2005	Examiner Marsano, F
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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EPO FORM 1503.03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 04 38 8090

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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09-03-2005

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
EP 0713000	A	22-05-1996	EP 0713000 A1	22-05-1996
			CN 1133391 A ,C	16-10-1996
			DE 59406785 D1	01-10-1998
			DK 713000 T3	16-11-1998
			JP 8144779 A	04-06-1996

US 3748850	A	31-07-1973	CA 951984 A1	30-07-1974
			ZA 7203057 A	28-02-1973

EP 1333192	A	06-08-2003	JP 2003222024 A	08-08-2003
			AU 2003200229 A1	21-08-2003
			CA 2416958 A1	30-07-2003
			CN 1435560 A	13-08-2003
			EP 1333192 A2	06-08-2003
			US 2003154937 A1	21-08-2003

GB 322161	A	26-11-1929	BE 360710 A	
			FR 675437 A	11-02-1930
