(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 548 251 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention
of the grant of the patent:
23.01.2008 Bulletin 2008/04

(51) Int Cl.:
F02B 75/20 *(2006.01)*

(21) Application number: **04388090.5**

(22) Date of filing: **15.12.2004**

---

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

Zweitakt-Motor mit interner Verbrennung und Gleichdruckturboaufgeladung mit 13 Zylindern in einer einzigen Reihe

Moteur à deux temps turbocompressé sous pression constante à combustion interne à 13 cylindres en ligne

---

(84) Designated Contracting States:
CH DE DK LI PL

(30) Priority: **17.12.2003 JP 2003419853**

(43) Date of publication of application:
29.06.2005 Bulletin 2005/26

(73) Proprietor: **MAN B&W DIESEL A/S**
2450 Copenhagen SV (DK)

(72) Inventors:
- **Hansen, Bo**
  2000 Frederiksberg (DK)
- **Ronnedal, Per**
  4000 Roskilde (DK)

(74) Representative: **Indahl, Peter Jensen et al**
Internationalt Patent-Bureau A/S
Rigensgade 11
1316 Copenhagen K (DK)

(56) References cited:

EP-A- 0 713 000	**EP-A- 1 333 192**
GB-A- 322 161	**US-A- 3 748 850**

- **"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**

Note: Within nine months from the publication of the mention of the grant of the European patent, any person may give notice to the European Patent Office of opposition to the European patent granted. Notice of opposition shall be filed in a written reasoned statement. It shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

Printed by Jouve, 75001 PARIS (FR)

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 their turbine side and with the scavenge air system on their compressor side, which engine has a firing sequence (n1 - n13) of the engine cylinders C1-C13.

[0002] EP 0 713 000 Al describes a two-stroke internal combustion engine having 13 cylinders in a single row, which engine has a firing sequence of the engine cylinders C1-C13Vibrations in the mechanical parts of the engine and structures connected to the engine are described, such as torsional vibrations in the shafting system, vibrations in the engine frame, and vibrations in the ship hull or superstructure. With the purpose of minimizing such vibrations in steel structures there is disclosed a group-wise ordering of the firing of cylinders and firing sequences fulfilling this group-wise ordering. There is no disclosure of turbocharging and no indication of vibrations in other structures than steel based structures.

[0003] EP 1 333 192 A2 describes a method of determining firing angles in four-stroke V-engines, and in two-stroke in-line engines having 7, 8 or 9 cylinders. The method determines firing angles that minimize an unbalanced couple acting as vibrating force. The types of vibrations mentioned are vibration of the engine main body, torsional vibrations in the engine shaft, and vibrations in pipings etc. connected to the engine. These vibrations are all in steel structures, viz, vibrations of mechanical systems. There is no indication of vibrations in other structures than steel based structures.

[0004] 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.

[0005] 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.

[0006] 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.

[0007] 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.

[0008] 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.

[0009] 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.

[0010] 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.

[0011] In a preferred embodiment the thirteen cylinders have a firing sequence (n1 - n13) so that the following requirement d) is also met

d)

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

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.

[0012] 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.

[0013] In a further embodiment the thirteen cylinders have a firing sequence (n1 - n13) so that the following requirement e) is also met

e)

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

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.

[0014] 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.

[0015] 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 Figs 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.

[0016] 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 Wartsilä 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.

[0017] 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.

[0018] 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.

[0019] 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.

[0020] 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.

[0021] 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.

[0022] 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 art row A via an air flow passage 24 and possibly an inlet air cooler 25 to a scavenge air system 26.

[0023] 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.

[0024] 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.

[0025] 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.

[0026] 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.

[0027] 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.

[0028] 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.

[0029] 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.

[0030] 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.

[0031] 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

(continued)

No.	Firing sequence for cylinders C1 to C13												
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.

[0032] 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°/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.

[0033] 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 1 between most of the cylinders, as illustrated in Fig. 2, except between cylinders C7 and C8 where the distance is l2 = 1 + 11, that is the normal distance l between cylinders plus an additional length 11 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 12 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.

[0034] 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.

[0035] 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°/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.

[0036] 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.

[0037] 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 l2 = 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.

[0038] 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°.

[0039] 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 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 C13. F(n) is consequently equal to 1 - 2 x (distance of cylinder Cn from cylinder C1)/ (total distance from cylinder C1 to cylinder C13).

[0040] 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.

[0041] 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.

[0042] 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 x -0.118 plus 0.7 x 0.7) = 0.71, which is well below the value of 1.8.

[0043] 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.

[0044] 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.

[0045] 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.

[0046] 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.

[0047] 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) + ((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)=7.74286, F(9)=8. 74286, F(10)=9.74286, F(11) =10.7429,F(12)=11.7429, and F(13)=12.7429.

[0048] With respect to the value for the 1 at 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.

[0049] 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.

[0050] 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.

[0051] 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.

[0052] 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.

[0053] 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

[0054] 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 that 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.

[0055] 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 Vgas(4)< 1.2 or Vgas(4)< 1.0. With respect to the gas pulsation, requirement b) can be limited to Vgas(5)< 1.2 or Vgas (5)< 1.0, and with respect to the gas pulsation, requirement c) can be limited to Vgas(6)< 1.2 or Vgas(6)< 1.0. Requirement d) can be limited to Vnick (1) < 1.5 or Vnick (1) < 1.3, and requirement e) can be limited to Vnick(2)< 3.0 or Vnick(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 (19), at least two turbochargers (20), and a scavenge air system (26) with at least one elongated scavenge air receiver (27), each cylinder having a scavenge air inlet connected to the scavenge air receiver (27) and an exhaust passage (18) leading into the at least one exhaust gas receiver (19), said turbochargers (20) being connected with the exhaust gas receiver (19) on their turbine side and with the scavenge air system (26) on their 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)

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

   far 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 with respect to the position of the cylinder between F(1) = 1 at cylinder C1 and F(13) = -1 at cylinder C13, and 11 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)

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

   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)

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

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
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 (10) between the firing of two consecutive cylinders is 360°/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 (10) between the firing of at least two pair of consecutively firing cylinders is different from 360°/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.

Patentansprüche

1. Zweitaktmotor mit interner Verbrennung und Gleichdruckturboaufladung mit dreizehn Zylindern in einer einzigen Reihe, wenigstens einem Abgassammelbehälter (19), wenigstens zwei Turboladern (20) und einem Spülluftsystem (26) mit wenigstens einem länglichen Spülluftsammelbehälter (27), wobei jeder Zylinder einen mit dem Spülluftsammelbehälter (27)verbundenen Spülluftteinlass und einen in den wenigstens einen Abgassammelbehälter (19) führenden Auslasskanal (18) aufweist und die Turbolader (20) auf ihrer Turbinenseite mit dem Abgassammelbehälter (19) und auf ihrer Kompressorseite mit dem Spülluftsystem (26) verbunden sind, und wobei dieser Motor eine Zündfolge (n1 - n13) der Motorzylinder C1 bis C13 aufweist, **dadurch ge- kennzeichnet, dass** die dreizehn Zylinder eine Zündfolge (n1 - n13) aufweisen, so dass wenigstens die folgenden drei Anforderungen a) bis c) erfüllt werden, für die Gaspulsation der 4. Ordnung

a)

$$V_{GAS}(4) = \left| \sum_{n=1}^{n=13} F(n) \cdot (\sin(4(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(4(\omega t + \varphi_n))) \right| < 1{,}8$$

für die Gaspulsation der 5. Ordnung
b)

$$V_{GAS}(5) = \left| \sum_{n=1}^{n=13} F(n) \cdot (\sin(5(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(5(\omega t + \varphi_n))) \right| < 1{,}8$$

für die Gaspulsation der 6. Ordnung
c)

$$V_{GAS}(6) = \left| \sum_{n=1}^{n=13} F(n) \cdot (\sin(6(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(6(\omega t + \varphi_n))) \right| < 1{,}8 \text{,}$$

wobei n die Zylinderzahl ist, φ_n der Zündwinkel für Zylinder n ist, F(n) eine Gewichtungsfunktion ist, die in Bezug auf die Position des Zylinders zwischen F(1) = 1 bei Zylinder C1 und F(13) = -1 bei Zylinder C13 linear interpoliert wird, und || die Länge des Vektors bezeichnet.

2. Zweitaktmotor mit interner Verbrennung und Gleichdruckturboaufladung nach Anspruch 1, **dadurch gekennzeichnet, dass** die dreizehn Zylinder eine Zündfolge (n1 - n13) aufweisen, so dass auch die folgende Anforderung (d) erfüllt wird, d)

$$V_{Nick}(1) = \left|\sum_{n=1}^{n=13} F(n)\cdot((\sin(\omega t+\varphi_n)+\sqrt{-1}\cdot\cos(\omega t+\varphi_n))\right| < 2{,}5\,,$$

wobei n die Zylinderzahl ist, φ_n der Zündwinkel für Zylinder n ist, F(n) eine Gewichtungsfunktion ist, welche F(1) = 0 bei Zylinder C1 und F(n) = F(n -1) + ((Abstand von der Mittellinie von Zylinder C_{n-1} zur Mittellinie von Zylinder C_n) /(Nennabstand zwischen Zylindern)) ist, und ‖ die Länge des Vektors bezeichnet.

3. Zweitaktmotor mit interner Verbrennung und Gleichdruckturboaufladung nach Anspruch 1 oder 2, **dadurch gekennzeich- net, dass** die dreizehn Zylinder eine Zündfolge (n1 - n13) aufweisen, so dass auch die folgende Anforderung (e) erfüllt wird,

e)

$$V_{Nick}(2) = \left|\sum_{n=1}^{n=13} F(n)\cdot((\sin(2(\omega t+\varphi_n))+\sqrt{-1}\cdot\cos(2(\omega t+\varphi_n)))\right| < 6{,}0\,,$$

wobei n die Zylinderzahl ist, φ_n der Zündwinkel für Zylinder n ist, F(n) eine Gewichtungsfunktion ist, welche F(1) = 0 bei Zylinder C1 und F(n) = F(n -1) + ((Abstand von der Mittellinie von Zylinder C_{n-1} zur Mittellinie von Zylinder C_n) /(Nennabstand zwischen Zylindern)) ist, und || die Länge des Vektors bezeichnet.

4. Zweitaktmotor mit interner Verbrennung und Gleichdruckturboaufladung nach einem der Ansprüche 1 bis 3, **dadurch gekenn- zeichnet**, **dass** die Zündfolge aus der Gruppe bestehend aus den folgenden Zündfolgen Nr. 1 bis Nr. 37 ausgewählt ist:

Nr.	**Zündfolge für Zylinder C1 bis 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	8	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

(fortgesetzt)

Nr.	Zündfolge für Zylinder C1 bis C13												
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. Zweitaktmotor mit interner Verbrennung und Gleichdruckturboaufladung nach einem der Ansprüche 1 bis 4, **dadurch gekennzeichnet**, **dass** die Zündfolge in dem Sinne gleichmäßig ist, dass der Drehwinkel der Kurbelwelle (10) zwischen den Zündungen von zwei aufeinander folgenden Zylindern 360°/13 ist.

6. Zweitaktmotor mit interner Verbrennung und Gleichdruckturboaufladung nach einem der Ansprüche 1 bis 4, **dadurch gekennzeichnet, dass** die Zündfolge in dem Sinne ungleichmäßig ist, dass der Drehwinkel der Kurbelwelle (10) zwischen den Zündungen von wenigstens zwei Paaren von nacheinander zündenden Zylindern verschieden von 360°/13 ist.

7. Zweitaktmotor mit interner Verbrennung und Gleichdruckturboaufladung nach einem der Ansprüche 1 bis 6, **dadurch gekennzeichnet, dass** er ein Hauptantriebsmotor in einem Containerschiff, vorzugsweise einem Containerschiff mit einer Kapazität von mehr als 10.000 TEU, ist.

8. Zweitaktmotor mit interner Verbrennung und Gleichdruckturboaufladung nach einem der Ansprüche 1 bis 7, **dadurch gekennzeichnet, dass** er eine maximale Leistung je Zylinder von wenigstens 5.000 kW hat.

Revendications

1. Moteur à deux temps turbocompressé sous pression constante à combustion interne, présentant 13 cylindres en une seule ligne, au moins un collecteur de gaz d'échappement (19), au moins deux turbocompresseurs (20) ainsi qu'un système d'air de balayage (26) avec au moins un collecteur d'air de balayage allongé (27), chaque cylindre présentant une entrée pour l'air de balayage reliée au collecteur d'air de balayage (27) et un passage d'échappement (18) débouchant dans ledit au moins un collecteur de gaz d'échappement (19), lesdits turbocompresseurs (20) étant reliés au collecteur de gaz d'échappement (19) sur leur côté turbine et au système d'air de balayage (26) sur leur côté compresseur, ledit moteur présentant un ordre d'allumage (n1-n13) des cylindres de moteur C1-C13, **caractérisé en ce que** les treize cylindres présentent un ordre d'allumage (n1- n13) permettant de remplir au moins les trois conditions a) à c) suivantes
pour la pulsation de gaz du 4^{e} ordre

a)

$$V_{GAS}(4) = \left| \sum_{n=1}^{n=13} F(n) \cdot (\sin(4(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(4(\omega t + \varphi_n))) \right| < 1{,}8$$

pour la pulsation de gaz du 5^{e} ordre b)

$$V_{GAS}(5) = \left| \sum_{n=1}^{n=13} F(n) \cdot (\sin(5(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(5(\omega t + \varphi_n))) \right| < 1{,}8$$

pour la pulsation de gaz du 6^{e} ordre

c)

$$V_{GAS}(6) = \left| \sum_{n=1}^{n=13} F(n) \cdot (\sin(6(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(6(\omega t + \varphi_n))) \right| < 1{,}8\,,$$

n étant le numéro du cylindre, φ_n étant l'angle d'allumage du cylindre n, F(n) étant une fonction de pondération interpolée linéairement par rapport à la position du cylindre entre F(1) = 1 au cylindre C1 et F(13) = -1 au cylindre C13, et identifiant la longueur du vecteur.

2. Moteur à deux temps turbocompressé sous pression constante à combustion interne selon la revendication 1, **caractérisé en ce que** les treize cylindres présentent un ordre d'allumage (n1 - n13) permettant de remplir également la condition d) suivante

d)

$$V_{Nick}(1) = \left| \sum_{n=1}^{n=13} F(n) \cdot ((\sin(\omega t + \varphi_n) + \sqrt{-1} \cdot \cos(\omega t + \varphi_n)) \right| < 2{,}5\,,$$

n étant le numéro du cylindre, φ_n étant l'angle d'allumage du cylindre n, F(n) étant une fonction de pondération qui est F(1) = 0 au cylindre C1 et F(n) = F(n-1) + ((distance de l'axe central du cylindre C_{n-1} jusqu'à l'axe central du cylindre C_n)/(distance nominale entre les cylindres)), et || identifiant la longueur du vecteur.

3. Moteur à deux temps turbocompressé sous pression constante à combustion interne selon la revendication 1 ou 2, **caractérisé en ce que** les treize cylindres présentent un ordre d'allumage (n1 - n13) permettant de remplir également la condition e) suivante

e)

$$V_{Nick}(2) = \left| \sum_{n=1}^{n=13} F(n) \cdot ((\sin(2(\omega t + \varphi_n)) + \sqrt{-1} \cdot \cos(2(\omega t + \varphi_n))) \right| < 6{,}0\,,$$

n étant le numéro du cylindre, φ_n étant l'angle d'allumage du cylindre n, F(n) étant une fonction de pondération qui est F(1) = 0 au cylindre C1 et F(n) = F(n-1) + ((distance de l'axe central du cylindre C_{n-1} jusqu'à l'axe central du cylindre C_n)/(distance nominale entre les cylindres)), et || identifiant la longueur du vecteur.

4. Moteur à deux temps turbocompressé sous pression constante à combustion interne selon l'une quelconque des revendications 1 à 3, **caractérisé en ce que** l'ordre d'allumage est choisi parmi le groupe constitué des ordres d'allumage n° 1 à n° 37 suivants:

N°	Ordre d'allumage des cylindres C1 à 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

(suite)

N°	**Ordre d'allumage des cylindres C1 à C13**												
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.

5. Moteur à deux temps turbocompressé sous pression constante à combustion interne selon l'une quelconque des revendications 1 à 4, **caractérisé en ce que** l'ordre d'allumage est égal en ce sens que l'angle de giration du vilebrequin (10) entre l'allumage de deux cylindres consécutifs est de 360°/13.

6. Moteur à deux temps turbocompressé sous pression constante à combustion interne selon l'une quelconque des revendications 1 à 4, **caractérisé en ce que** l'ordre d'allumage est inégal en ce sens que l'angle de giration du vilebrequin (10) entre l'allumage d'au moins deux paires de cylindres s'allumant consécutivement diffère de 360°/13.

7. Moteur à deux temps turbocompressé sous pression constante à combustion interne selon l'une quelconque des revendications 1 à 6, **caractérisé en ce que** le moteur est un moteur de propulsion principale dans un navire porte-conteneur, de préférence un navire porte-conteneur avec une capacité de plus de 10.000 TEU.

8. Moteur à deux temps turbocompressé à combustion interne selon l'une quelconque des revendications 1 à 7, **caractérisé en ce que** le moteur présente une puissance maximale par cylindre d'au moins 5000 kW.

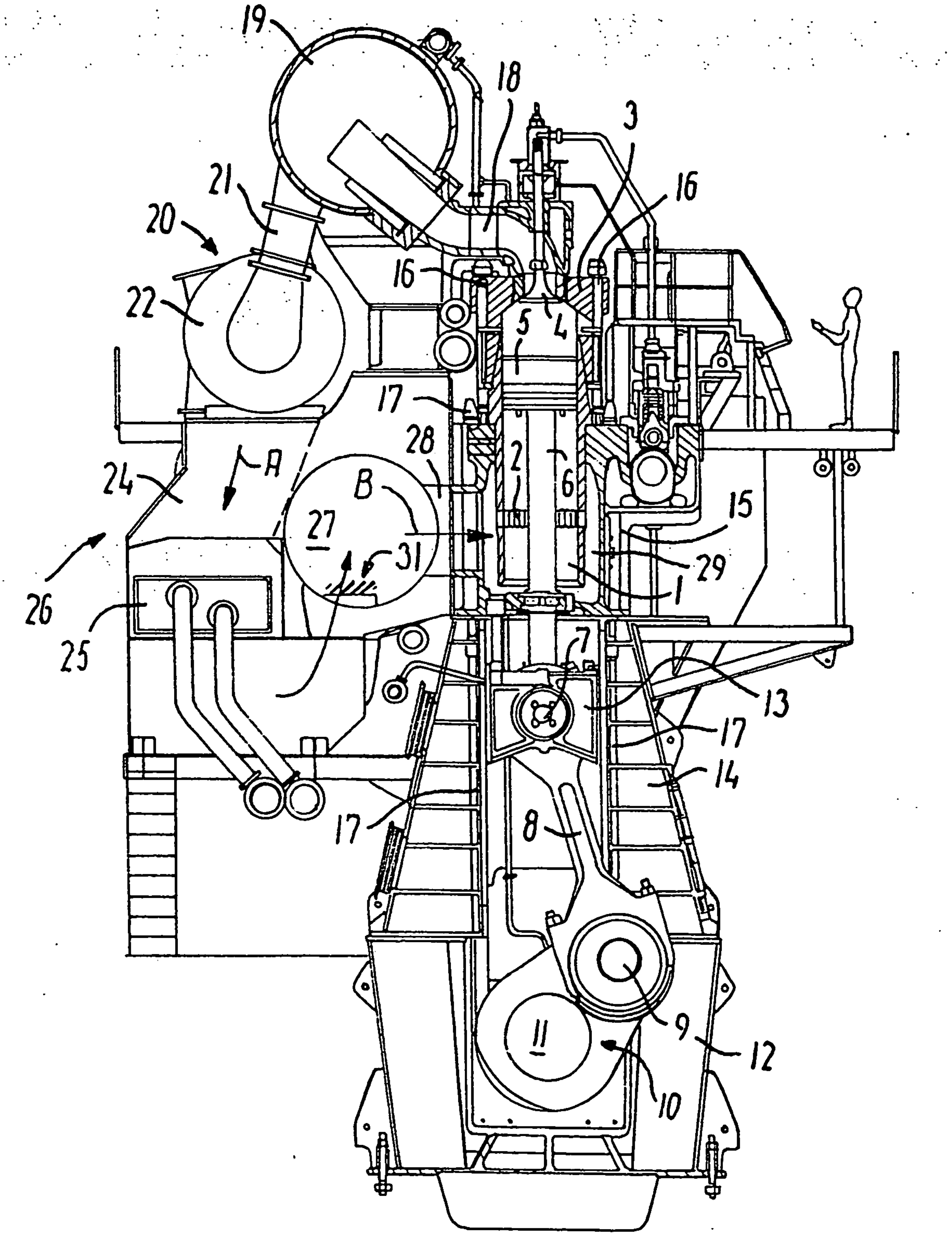
19
18
3
21
16
20
16
22
5
4
17
28
2
6
24
A
B
15
27
31
29
26
1
25
7
13
17
14
17
8
9
12
11
10

FIG.1

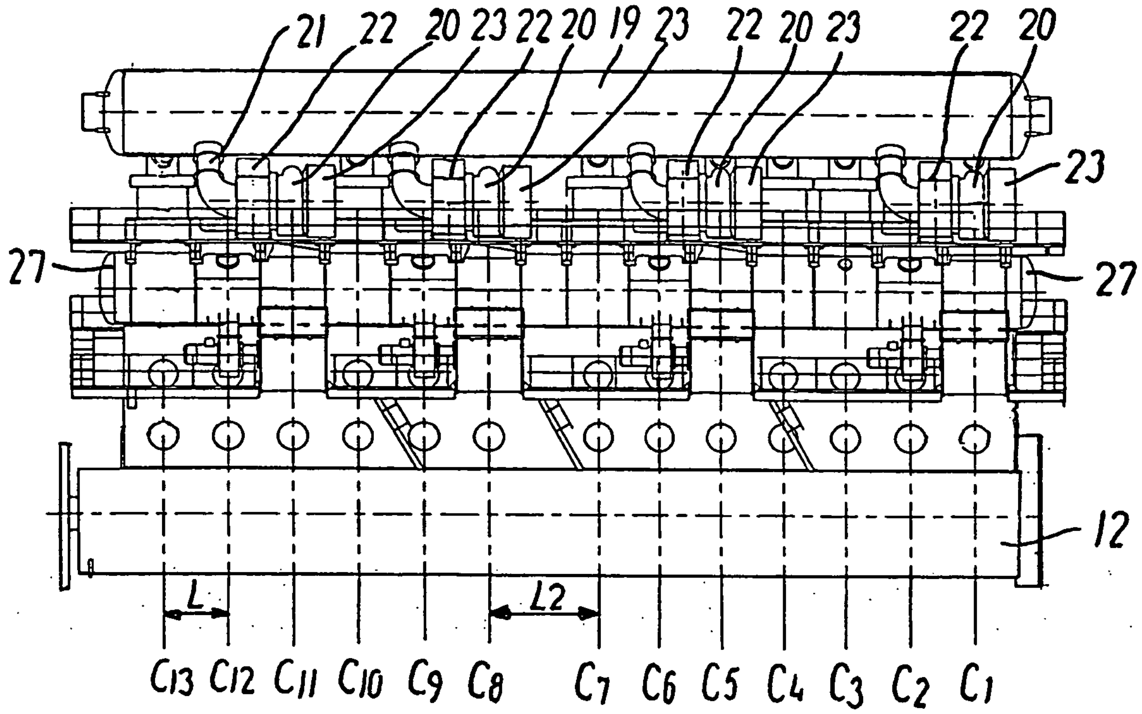
21
22
20
23
22
20
19
23
22
20
23
22
20
23
27
27
12
L
L2
C13
C12
C11
C10
C9
C8
C7
C6
C5
C4
C3
C2
C1

FIG. 2

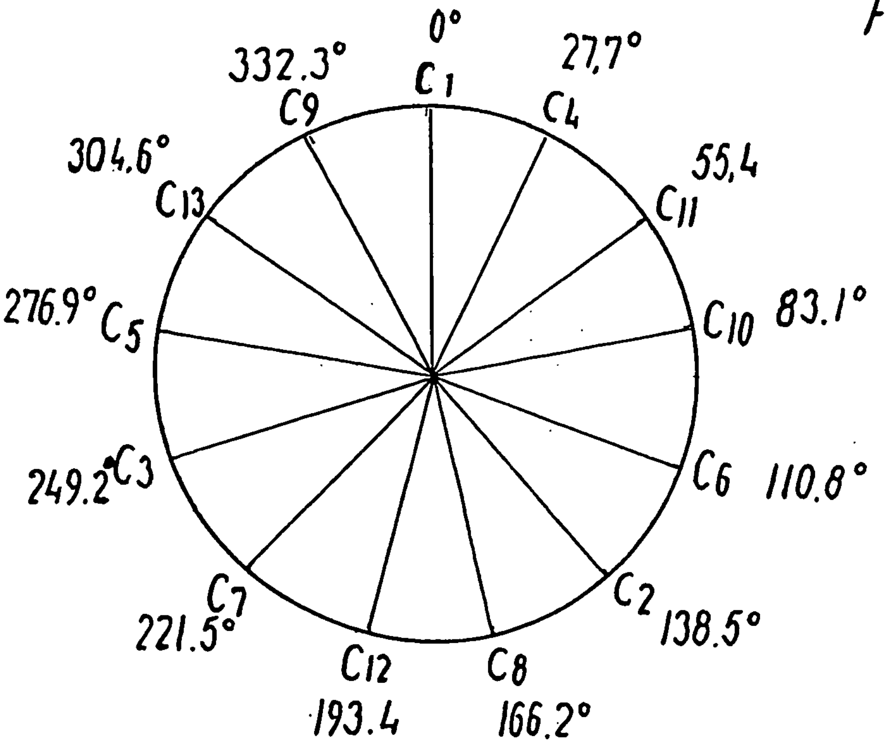
0°
C1
27,7°
C4
55,4
C11
83.1°
C10
110.8°
C6
138.5°
C2
166.2°
C8
193.4
C12
221.5°
C7
249.2
C3
276.9°
C5
304.6°
C13
332.3°
C9

FIG. 4

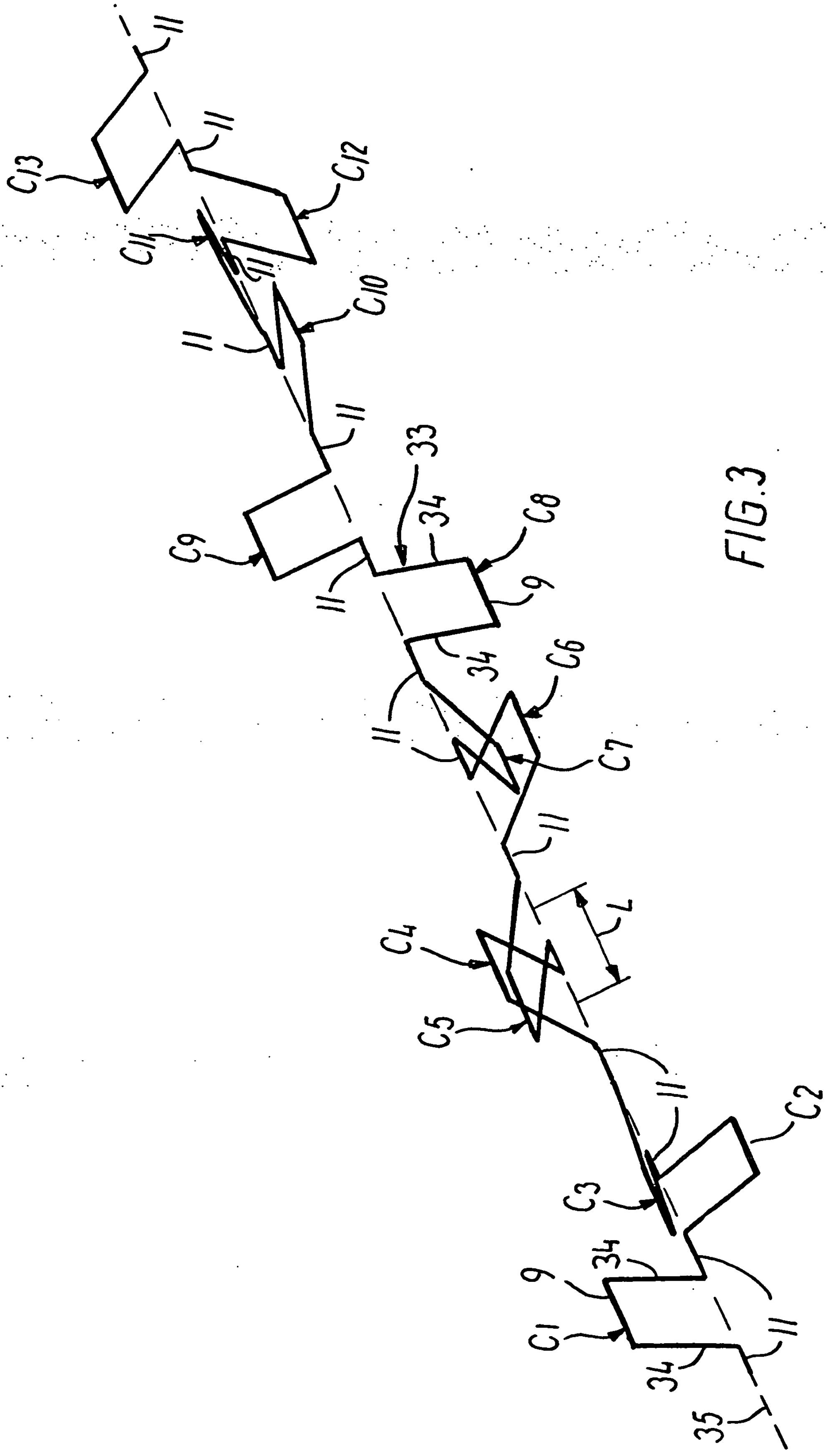
11
C13
11
C12
C11
11
C10
11
11
C9
11
33
34
C8
9
34
C6
11
C7
11
L
C4
C5
11
C2
C3
34
9
11
C1
34
35

FIG.3

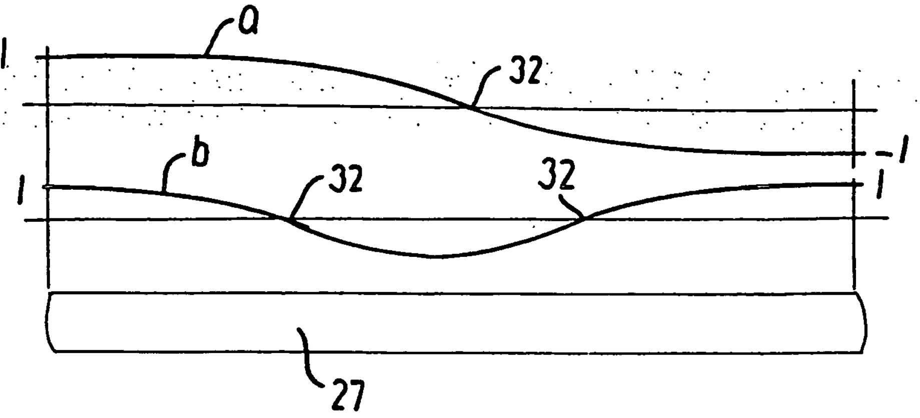

FIG.5

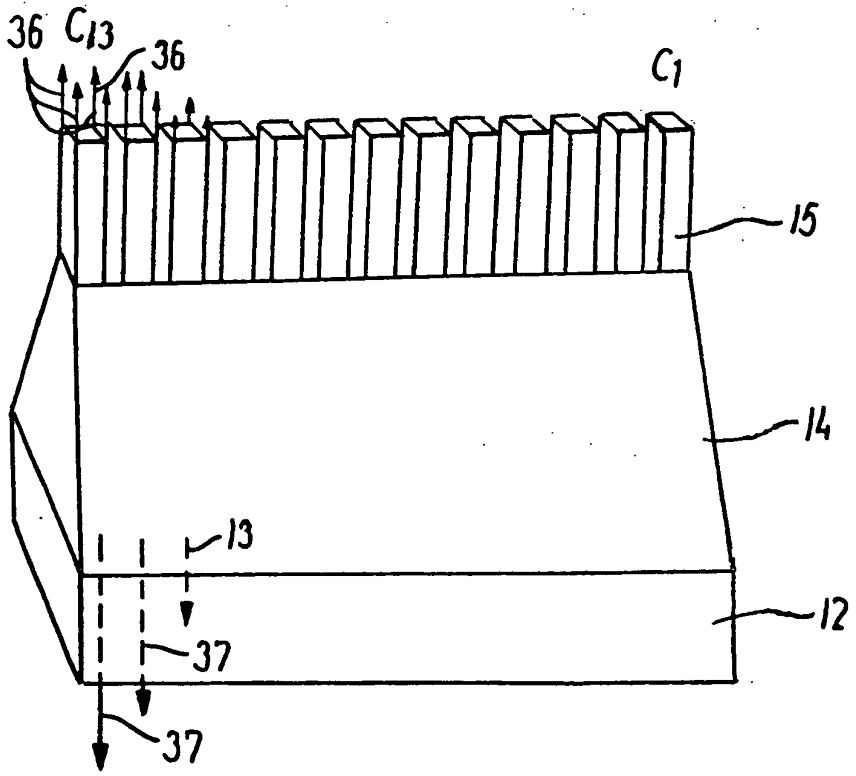

FIG.6

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- EP 0713000 A **[0002]**
- EP 1333192 A2 **[0003]**