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(54) **Title**: IMPROVING POWER CONSUMPTION IN A COMPRESSOR

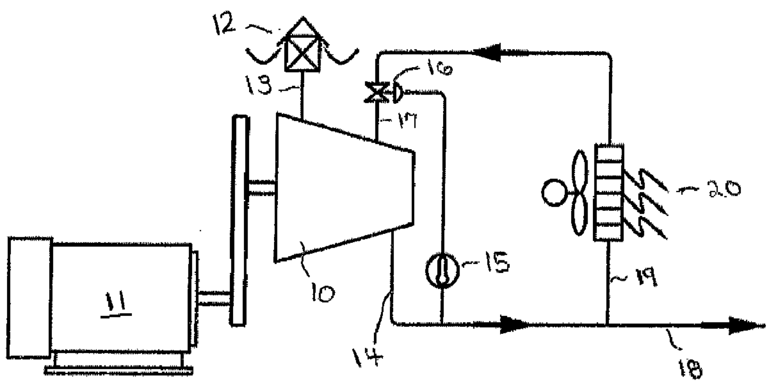


FIGURE 1

(57) **Abstract**: An apparatus for and method of optimizing power consumption in a compressor by closely matching the compressors built in compression with the compressors discharge pressure.

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# IMPROVING POWER CONSUMPTION IN A COMPRESSOR

## CROSS-REFERENCE OF RELATED APPLICATIONS

This application is an international application which claims the benefit of U.S. Provisional Patent Application No. 61/736,621 filed on 13 December 2012.

## BACKGROUND OF THE INVENTION

The present invention relates to a compressor having improved power consumption and a method for optimizing the performance of, and improving the power used by, a compressor.

In all compressors, the ideal condition is to match the built in compression of the machine to the discharge pressure. Built in compression is engineered into the machine based on the geometry and the location of the discharge port. The actual built in compression pressure varies from the engineered designed values based on the ambient temperature and elevation above sea level (ambient pressure) at the compressor intake.

Matching the built in compression of the machine to the discharge pressure is difficult, if not impossible to do, in a “fixed geometry” machine, such as an oil free compressor.

Therefore, it is an object of this invention to have a method to have the built in compression in a compressor to closely approach or to equal the compressor’s discharge pressure.

The present invention is operable on both oil flooded compressors and oil free compressors.

SUMMARY OF THE INVENTION

The present invention presents a novel method of and apparatus for optimizing power consumption in a compressor. The invention is applicable particularly to positive displacement compressors including oil and non-oil flooded compressors including screw compressors and sliding vane compressors.

Power consumption is optimized by the invention's method of matching the built in compression in a compressor pocket to the compressor's discharge pressure, in a thermodynamic fashion, that is without mechanically varying the mechanical displacement of the compressor cylinder. The method of the invention utilizes air flow to the practitioner's advantage by throttling the flow of compression air into a captive compressor pocket located immediately prior to the discharge port and, more specifically, by varying the flow of air into the captive pocket based on the discharge temperature of the compressed air exiting the compressor.

The ideal condition is to match the built in compression of the machine to the discharge pressure as the machine is in operation. Unfortunately, in the past this was impossible to do using a fixed geometry machine when the discharge pressure changes with the demand of the process. Extra shaft power (up to +10%) is required anytime the discharge pressure is not closely matched to the built in compression (over or under compression).

It has been surprisingly discovered that adjusting (such as by using a thermostatic control valve) the flow of cooled compressed air, such as recirculated cooled compressed air, into a compressor at a specific location based on variances from a preset discharge temperature ( which correlates to the set discharge pressure) will thereby serve to maintain or more closely approach the set discharge pressure, and the built in compression in the compressor will move toward matching the compressor's discharge pressure. Preferably, this adjustment will be done automatically. This method is desirable in that a compressor's discharge pressure can vary based on how the air (or gas) is used in the process.

For the purposes of the invention, "built in compression" is the pressure in a compressor's captive pocket just prior to the pocket opening to the discharge port. In a sliding vane compressor it is the pressure in a compressor's captive pocket just prior to the leading vane of the pocket opening to the discharge port.

Most fixed geometry compressors do not have real fixed discharge pressures, and in reality discharge pressures can vary considerably from time to time. As a result, fixed geometry compressors are not able to operate at the built in compression on a consistent basis and there can be over compression, which means that the built in compression in the captive pocket (in a sliding vane compressor the pocket just prior to when the leading vane opens to the discharge port) is higher than the discharge pressure, or under compression, which means the built in compression in the captive pocket is lower than the discharge pressure.

## DESCRIPTION OF THE DRAWINGS

The above and other objects, features, and advantages will become more readily apparent from the following description, reference being made to the accompanying drawing in which:

Figure 1 is a flow schematic of the present invention.

Figure 2-4 depicts a partial cross sectional view of showing the sequential operation of the present invention, in this example on a sliding vane compressor.

## DESCRIPTION OF THE INVENTION

Figure 1 depicts a flow schematic of the compressor system of the present invention. The fluid compressed may be air or a gas. Compressor 10 is powered by main motor 11. For example, if the fluid is ambient air, it initially will pass through inlet air filter 12 and be introduced into compressor 10 via inlet line 13. Compressed air is discharged from the compressor via outlet line 14. The temperature of the discharged air is taken at temperature sensor 15, and the temperature is relayed (using wireless or wired connections) to automatic thermostatic control valve 16, which utilizes the measured temperature to regulate the added flow of compressed air to the compressor from line 17 to thereby maintain a constant discharge temperature. Temperature/air input control valve 16 will open or close based on the temperature of the compressed air discharged from the compressor via outlet line 14. If the temperature of the compressed air in 14 is lower than the value set by the operator as being the desired exit temperature the valve 16 will be closed and air will not flow into the compressor from line 17into a specific region of the compressor as described in detail below. The valve will remain closed until the discharge temperature of the compressed air in 14 rises to the desired exit temperature. If the temperature of the exit compressed air in 14 is higher than the desired value the valve 16 will be opened to insert cooled compressed air into the compressor until the temperature measured at 14 drops to the desired exit temperature. The control valve can be either thermostatically controlled (mechanical bulb type) or electronically controlled in conjunction with sensors used to measure discharge temperature.

The mass flow of air at 14 is the sum of the ambient air initially inserted into the compressor from 13 and the air inserted from 17.

Compressed air from line 14 is sent downstream via line 18, with a portion being separated off via line 19 to be used in the process of the present invention. This latter air is directed to cooler 20 to remove heat. The amount of cooling can be significant. For example, a typical temperature of compressed air discharged can from a sliding vane compressor can be in the range of from approximately 350-400°F, and such air will typically be cooled to approximately 100-115°F. for use in the process of the invention. Cooler 20 can also serve as a reservoir if needed. The air from cooler 20 is directed to valve 16, where it is throttled into the compressor as needed based on the exit air temperature. Alternatively, a supplemental source of compressed air, or cooled compressed air, other than air from line 14 can be used in the process.

Figure 2-4 depicts one embodiment of the present invention utilizing a sliding vane compressor.

A “sliding” rotary vane compressor is a positive displacement machine that uses a rotor, which may be, but is not necessarily, eccentric, placed within a cylindrical chamber that is located within a rotor housing and is used to compress compressible fluids such as gases. The rotor has slots along its length, and each slot contains a blade, i.e. a vane. The vanes are thrown outwards by centrifugal force when the compressor is running and the vanes move in and out of the slot and follow the contour of the inner chamber wall. The vanes create individual cells, i.e. pockets, of gas which, because of the vanes’ movement from the fluid inlet to outlet, are compressed as the rotor turns. The vanes sweep the cylinder, sucking air in on one side and ejecting it on the other. As each cell approaches the discharge port, its volume is reduced and the compressed fluid is discharged.

In the examples of Figures 2-4, it is assumed that the temperature measured at point 15 is above the exit gas temperature desired by the practitioner. Therefore, during the entire sequence of Figures 2-4 valve 16 is open and air is being throttled into the compressor in the manner described below.

In the compressor 100 of Figure 2, ambient air A that will undergo compression enters at air inlet 110 and compressed air B exits at discharge port 111. Rotor 200 is located within housing 105 and rotates in the direction of arrow R. A plurality of compression pockets, pockets 101, 102, 103 and 104 being examples, are formed in the space between the outer surface of the rotor and the inner surface of the housing . These pockets are further defined , in a sliding vane compressor, by adjacent vanes, for example, adjacent vanes 202 and 203 define pocket 102. Because of the eccentric placement of the rotor each succeeded pocket as the rotor rotates in direction R will be smaller as the pockets approach discharge port 111, and will increase in size thereafter. The decrease in size of the pockets will cause a compression of the air within such pockets With specific reference to pocket 101, which is formed by vanes 201 and 202, and pocket 102, which is formed by vanes 202 and 203, air C, which corresponds to the air entering the compressor through open valve 16 and line 17 in Figure 1, will begin to enter pocket 101 from supplemental air injection port 112 as soon as vane 202 opens up pocket 101 to air intake 112, and will continue to enter pocket 101 as long as the pocket is captive, that is, up until the point that leading vane 202 opens up to discharge port 111. With regard to the designation of vane 202 as a ‘leading vane”, it is understood that vane 202 functions as the leading vane to pocket 101 and the trailing vane to pocket 102, based on the direction of rotation of rotor 200.

The location of air injection point 112 is important to the invention. Air has to be injected into a captive pocket that is located immediately prior to the pocket (in Figure 2 pocket 102) that is open up to, i.e. discharging compressed air through, injection port 111. The geometry of the sliding vane compressor of Figures 2-4 is such that (a) when leading vane 203 is just opening up to discharge port 111 to pocket 102; (b) trailing vane 202 is closing off pocket 102 from injection port 112. It is a feature of this invention that air C will only continue to be injected into and pressurize pocket 101 as long as it remains a captive pocket. Air will not be injected into pocket 101 when, it stops being a captive pocket due to its rotation in direction R; that is, air can no longer be injected into pocket 101 at the point where pocket 101 opens up to discharge port 111. Adjacent vanes in a compressor are located such that a pocket will never receive air through port 112 while the pocket is discharging air through port 111.

It is an aspect of this invention that inlet 112 is located on the compressor such that the pocket into which air C is injected is located immediately before (in the direction of rotation) the pocket at which air is being discharged via discharge port 111. Put another way, because the “injection pocket” (pocket 101 in Figure 2) immediately precedes the “discharge pocket” (pocket 102 in Figure 2) in the direction of rotation of rotor 200, there will be no further compression in any pocket in which air C is injected after such injection ceases and the discharge of air through port 111 begins essentially immediately after the cessation of the injection of air into a particular pocket. This would not be the case if inlet 112 was located one pocket further removed from discharge port 111, such as at point X, and was therefore injecting air into, for example, pocket 103 as air was discharging from pocket 102. If such were the case, severe over compression could occur since there would be additional compression of the air after pocket 103 rotated away from inlet 112 and into the position where pocket 101 is in Figure 2. Such over compression can result in a significant increase in horsepower and possible mechanical failure, such as blade breakage or worse.

With reference to Figure 3, the injection of air C continues while pocket 101 remains captive. In this situation there is air injection while the pocket continues to undergo significant volume reduction, which results in the pressure in the pocket increasing at a faster rate than it would under normal compression.

With reference to Figure 4, the injection of air into pocket 101 ends just prior to the leading vane 104 passing discharge port 111 and therefore pocket 101 is no longer captive. By practicing the invention as described, the built in compression in pocket 101 immediately before a pocket begins to open up to the discharge port should equal the discharge pressure, thus minimizing the power consumption compared to when there is over or under compression in the compressor. If has been surprisingly discovered that by regulating the discharge temperature in the manner described the built in pressure in the captive pocket will begin to approach the discharge pressure.

Therefore, if the operator wishes to run the compressor at a constant fixed temperature, for example 380°F, then regardless of variances in the discharge pressure it will match the pressure within the captive pocket located immediately prior to the discharge port.

The opening and closing of valve 16 based upon variances from the desired discharge temperature can be accomplished automatically. Therefore, the method of the invention accomplishes at least the following:

(a) By using a control valve to thermostatically maintain the discharge temperature at a fixed level, the volume (mass) of air injected into the captive pocket is almost perfectly matched to the built in compression to thereby match the pressure in the captive pocket to the discharge pressure;

(b) the compressor therefore operates at the ideal shaft power; and

(c) the captive pocket just prior to the fluid outlet is neither over-pressurized nor under-pressurized.

The method of the present invention is adaptable to be utilized with any type of compressible fluid, including gases such as air, digester gas, nitrogen and carbon dioxide.

It is to be understood that the form of this invention as shown is merely a preferred embodiment. Various changes may be made in the function and arrangement of parts; equivalent means may be substituted for those illustrated and described; and certain features may be used independently from others without departing from the spirit and scope of the invention as defined in the following claims.

What is claimed is:

1. A fluid compressor comprising:

a) a housing in which there are a plurality of compression pockets, with each compression pocket adaptable for holding a fluid;

b) a first fluid inlet through which fluid can be injected into a compression pocket;

c) a fluid outlet into which a compression pocket can release compressed fluid; each of the plurality of compression pockets being in turn rotatable in the same direction from the first fluid inlet to the fluid outlet, wherein the volumetric capacity in each of said plurality of compression pockets is reduced as each of said plurality of compression pockets rotates from the fluid inlet to the fluid outlet to thereby compress the fluid within each of said plurality of compression pockets;

d) a second fluid inlet through which cooled compressed fluid is injected into one of said plurality of compression pockets as said pocket is being rotated, said fluid inlet being located such that immediately after receiving the compressed fluid from said second fluid inlet said one of said plurality of compression pockets will open onto and discharge compressed fluid into the fluid outlet;

e) a temperature sensor to (i) measure the temperature of compressed fluid after said compressed fluid is released from the fluid outlet and (ii) compare said measured temperature to a predetermined fluid exit temperature; and

f) means to direct cooled compressed fluid to said second fluid inlet for insertion into a compression pocket when the measured temperature is above the predetermined temperature.

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2. The compressor of claim 1 which is a sliding vane compressor.

3. The compressor of claim 1 wherein the means to direct cooled compressed fluid to said second fluid inlet comprises a cooler adaptable to receive a portion

compressed fluid from the fluid outlet for cooling, a conduit through which cooled compressed fluid is deliverable from the cooler to the second fluid inlet and a control valve for regulating the flow of cooled compressed fluid through the conduit to the second fluid inlet based on the measured temperature of the compressed fluid released from the fluid outlet.

4. A method of optimizing power consumption in a fluid compressor having internal pockets in which fluid is compressed, comprising
(a) determining an desired discharge temperature for compressed fluid exiting the compressor, said desired discharge temperature being correlated from a pre-set discharge pressure for the compressor;
(b) inserting fluid to be compressed into the compressor through a first fluid inlet into a pocket of a compressor;
(c) withdrawing compressing fluid from the compressor through a fluid outlet;
(d) measuring the temperature of the compressing fluid exiting the temperature and comparing said measured temperature to the desired discharge temperature, and
e) inserting, when the measured temperature is above the desired discharge temperature, cooled compressed fluid into the compressor into a pocket that is located within the compressor where such inserted cooled air will not be subject to further compression once the injection of air into the pocket ceases.

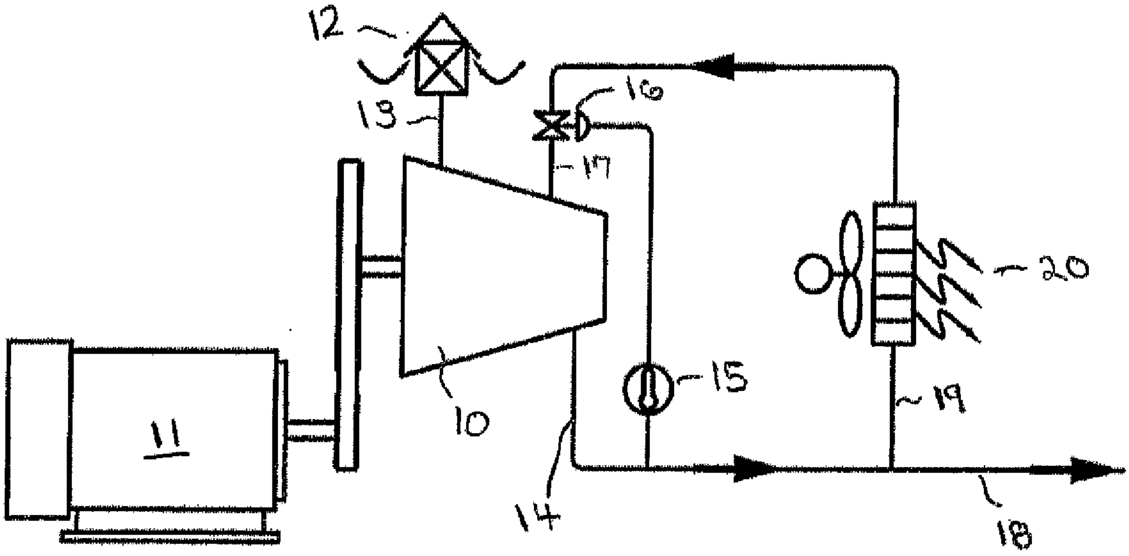


FIGURE 1

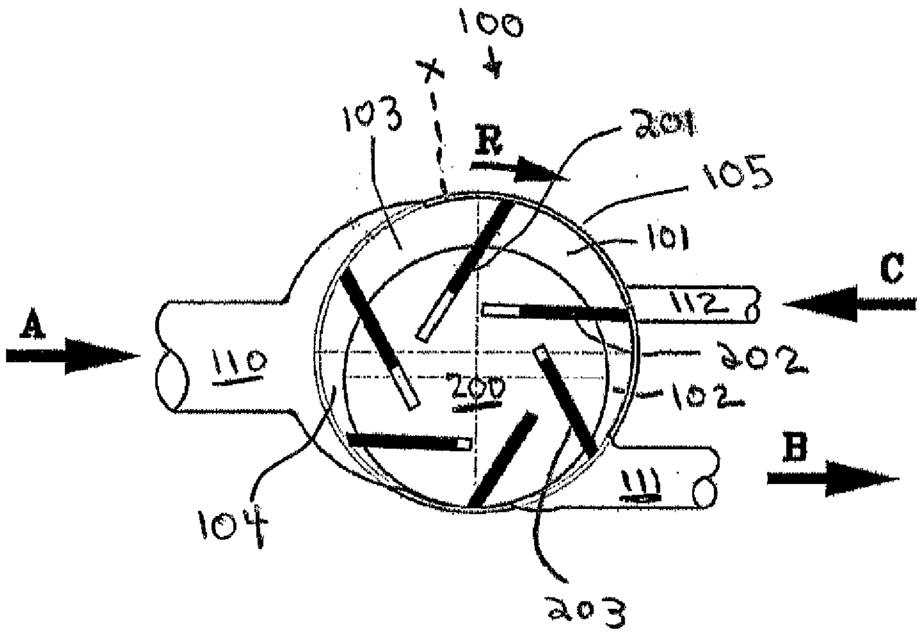


FIGURE 2

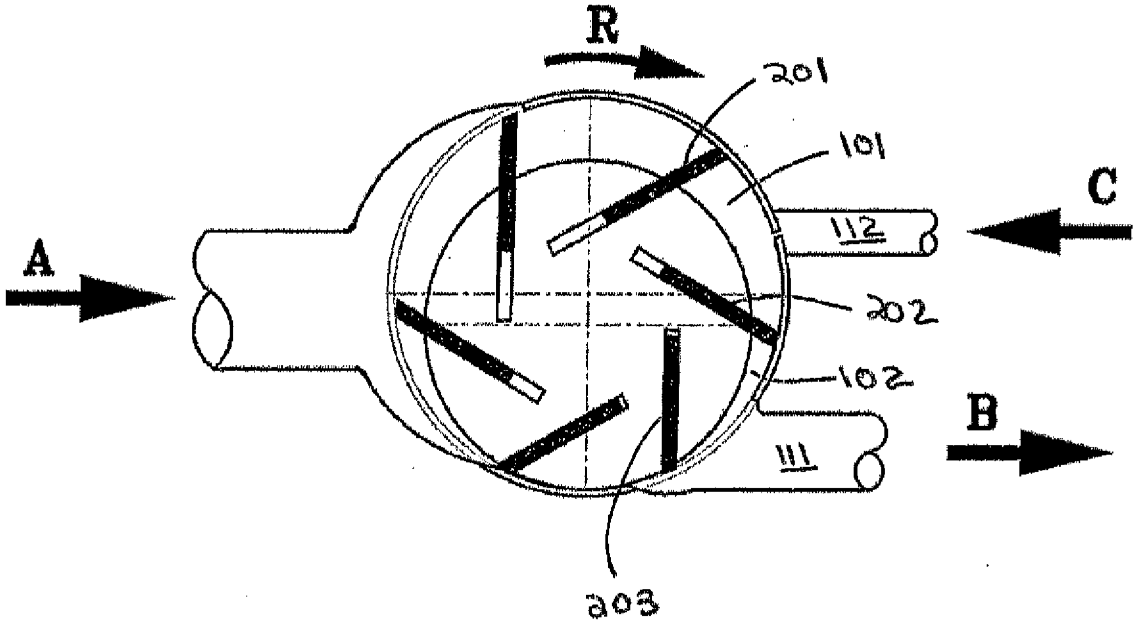


FIGURE 3

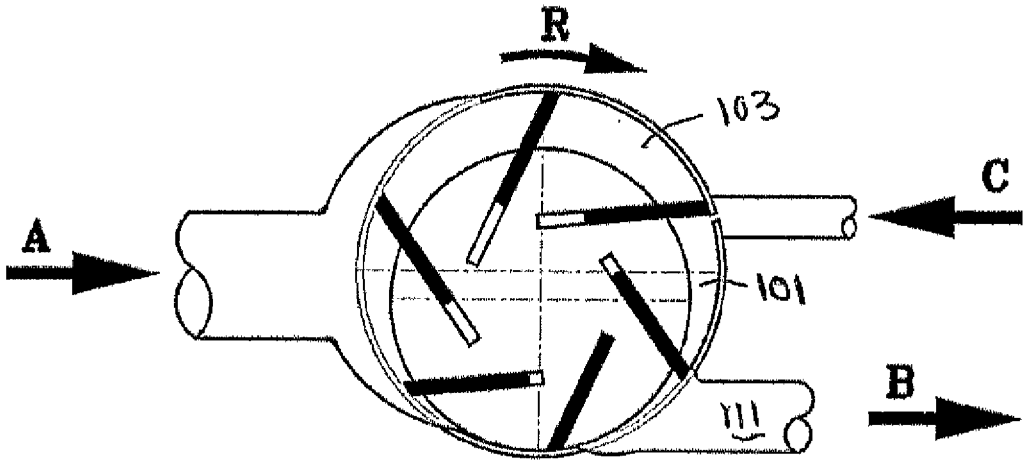


FIGURE 4

**INTERNATIONAL SEARCH REPORT**

International application No.

PCT/US 2013/074934

A. CLASSIFICATION OF SUBJECT MATTER

***F04C 29/04*** *(2006.01)*
***F04C 29/12*** *(2006.01)*
***F04C 18/344*** *(2006.01)*

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F01C 1/00, 1/30-1/46, 21/00, 21/06, 21/18, F04C 18/00, 18/30-18/46, 29/00, 29/04, 29/12

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatSearch (RUPTO internal), USPTO, PAJ, Esp@cenet, DWPI, EAPATIS, PATENTSCOPE, Information Retrieval System of FIPS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y | WO 2009/145898 A1 (FLSMIDTH et al.) 03.12.2009, p. 2, lines 15-17, p. 3, line 29-p. 4, line 15, p. 6, line 12-p. 7, lines 6, 23-28, fig. 1, 4 | 1-4 |
| Y | RU 2366833 C1 (OTKRYTOE AKTSIONERNOE OBSCHESTVO "TATARSKY NAUCHNO-ISSLEDOVATELSKY I PROEKTNO-KONSTRUKTORSKY INSTITUT NEFTYANOGO MASHINOSTROENIYA" (OAO "TATNIINEFTEMASH")) 10.09.2009, p. 6, lines 39-44 | 1-4 |
| A | US 1893171 A (EMIL KAGI) 03.01.1933 | 1-4 |
| A | JP H 02264186 A (DIESEL KIKI CO LTD) 26.10.1990 | 1-4 |

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| Date of the actual completion of the international search | Date of mailing of the international search report |
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| 05 March 2014 (05.03.2014) | 20 March 2014 (20.03.2014) |

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