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

(11) Publication number: 0 104 265 A1

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 82108865.5

(22) Date of filing: 24.09.82

(51) Int. Cl.^{3}: F 04 C 18/16

(43) Date of publication of application: 04.04.84 Bulletin 84/14

(84) Designated Contracting States: DE FR GB IT NL SE

(71) Applicant: Hitachi, Ltd.
5-1, Marunouchi 1-chome
Chiyoda-ku Tokyo 100(JP)

(72) Inventor: Kasuya, Katsuhiko
1993-114, Shimoinayoshi Chiyodamura
Niihari-gun Ibaraki-ken(JP)

(72) Inventor: Mori, Hidetomo
195-2, Asahicho Tomobemachi
Nishiibaraki-gun Ibaraki-ken(JP)

(72) Inventor: Fujiwara, Mitsuru
2361-8, Oaza Anjiki Dejimamura
Niihari-gun Ibaraki-ken(JP)

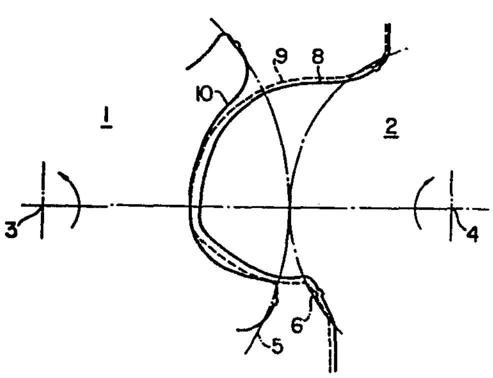
(72) Inventor: Matsunaga, Tetsuzo
85-14, Shoei Sakuramura
Niihari-gun Ibaraki-ken(JP)

(74) Representative: Finck, Dieter et al,
Patentanwälte v. Füner, Ebbinghaus, Finck Mariahilfplatz 2 & 3
D-8000 München 90(DE)

(54) Screw rotor.

(57) In a screw compressor including a female rotor and a male rotor rotating while meshing with each other, the rotor tooth form (8) of one of the female and male rotors meshing with each other without any clearance therebetween in normal temperature condition is used as a basic tooth form for obtaining a rotor tooth form (9) produced by deformation on account of thermal expansion during operation. The tooth form thus obtained is used for generating another rotor tooth form (10), and the rotor tooth form thus generated is used to obtain a rotor tooth form which is a normal temperature version of the thermally deformed tooth form, to thereby use the rotor tooth form of the normal temperature version for the other of the female and male rotors. In deciding the rotor tooth form, the backlash of synchronizing means may also be taken into cinsideration in addition to the influences of thermal expansion.

FIG. 2



EP 0 104 265 A1

0104265

SCREW ROTOR

1 BACKGROUND OF THE INVENTION

This invention relates to screw rotors of screw compressors, and more particularly it deals with screw rotors suitable for use with a dry type screw compressor in which the rotors are made to rotate while meshing with each other by synchronizing means, without the rotors coming into contact with each other.

Generally, in screw compressors of the oilless type suitable for use in applications where mingling of oil in the gas discharged from a screw compressor is not desirable, transmission of rotation between screw rotors forming a pair is effected through synchronizing means mounted at shaft portions outside the working chambers of the rotors, and at this time the rotors rotate while meshing with each other witout coming into contact with each other. The screw rotors of this type of screw compressors have their teeth heated to a higher temperature during operation than the screw rotors of an oil-cooled type screw compressor in which oil is injected into the working chambers for the rotors to mesh with each other in so as to lubricate, cool and seal the two rotors, so that the teeth are subjected to thermal deformation during operation and their shape greatly differs during operation from their shape in inoperative condition in which the temperature is normal. Thus when the two rotors are designed, it is necessary to select a dimensional relation for them in such a manner that the rotors are prevented from coming into contact with each other and with the casing while a minimum clearance is kept therebetween during operation.

In rotor design of the prior art, however, it has hitherto been usual practice to decide the clearance between the two rotors and between the rotors and the casing roughly, so that the clearances provided between the rotors and between the rotors and the casing have no theoretical basis. This has cuased problems to arise with regard to the efficiency of the screw compressors.

More specifically, in one process known in the art for providing a clearance between the two rotors of a screw rotor that has been put to practical use, a basic tooth form is given to the male rotor, for example, and a predetermined clearnace is provided in the direction of the normal to the tooth form of the female rotor by taking into consideration deformation of the rotors that would occur on account of thermal expansion during operation.

This process for deciding the clearance between the rotors is not considered best because the clearance given to the rotors by this process does not have an optimum value selected by studying in detail the thermal expansion of the rotors and the clearance between the rotors as measured during operation, since the tooth from will undergo deformation in different manners on account of thermal expansion and the deformation may vary depending on the tooth form of the rotors.

In another process known in the art for providing a clearance to the rotors, a smaller clearance is given to the rotors in a region in which relative sliding movement between the teeth of the rotors meshing with each other is small and a larger clearance is given to the teeth of the rotor in other regions. Such process is disclosed in US Patent No. 3,414,189, for example.

However, this process would not be considered to quantitatively take into consideration the thermal deformation to which the two rotors of the screw compressor would be subjected during operation.

SUMMARY OF THE INVENTION

An object of this invention is to provide a screw rotor capable of maintaining a minimum clearance between a male rotor and a female rotor of a screw compressor during operation through the entire region of the tooth forms of the rotors meshing with each other, to thereby greatly improve the performance of the screw rotor.

Another object is to provide a screw rotor capable of preventing a female rotor and a male rotor of a screw compressor from coming into contact with each other during operation by taking backlash of the synchronizing gears into consideration, to thereby improve the reliability of the screw compressor.

Still another object is to provide a screw rotor capable of greatly improving performance by taking into consideration a temperature distribution axially of the rotor both inside and outside thereof.

To accomplish the aforesaid objects, there is provided, in a screw compressor comprising a female rotor and a male rotor rotating about two axes parallel to each other while in meshing engagement with each other, a screw rotor in which the rotor tooth form of one of the femald and male rotors meshing with each other without any clearance therebetween in normal temperature condition is used as a basic tooth form for obtaining a rotor tooth form produced by deformation on account of thermal expansion during operation; the rotor tooth form thus obtained is used for generating another rotor tooth form; and the rotor tooth form thus generated is used to obtain a rotor tooth form which is a normal temperature version of the thermally deformed tooth form, to thereby use the rotor tooth form of the normal temperature version for the other of the female and male rotors.

To accomplish the aforesaid objects, there is further provided, in a screw compressor comprising a female rotor and a male rotor meshing but without coming into contact with each other for rotation about two parallel axes through synchronizing means, a screw rotor in which the rotor tooth form of one of the female and male rotors meshing with each other without any clearance therebetween in normal temperature condition is used as a basic tooth form for obtaining a rotor tooth form produced by deformation on account of thermal expansion during operation; the rotor tooth form thus obtained is used for generating another tooth form; the rotor tooth form thus generated is used to obtain a rotor tooth form by reducing an amount corresponding to the backlash of the synchronizing means; and the rotor tooth form thus obtained is used to obtain a rotor tooth form which is a normal temperature version of the thermally deformed tooth form, to thereby use the rotor tooth form of the normal temperature version for the other of the female and male rotors.

To accomplish the aforesaid objects, there is further provided, in a screw compressor comprising a female rotor and a male rotor meshing but without coming into contact with each other for rotation about two parallel axes through synchronizing means, a screw rotor in which the rotor tooth form of one of the female and male rotors meshing with each other without any clearnace therebetween in normal temperatuare condition is used as a basic tooth form for obtaining a rotor tooth form produced by deformation on account of thermal expansion during operation; another tooth form is obtained by adding to the rotor tooth form thus obtained amounts of thermal deformation and the backlash of the synchronizing means occurring during operation; the rotor tooth form thus obtained is used to generate another rotor tooth form; and the rotor tooth form thus obtained is used to obtain a rotor tooth form which is a normal temperature version of the thermally deformed tooth form, to thereby use the rotor tooth form of the normal temperature version for the other of the female and male rotors.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a view in explanation of the basic tooth form of the screw rotor according to the invention;

Figs. 2-5 shows a first embodiment of the screw rotor in conformity with the invention, in explanation of a process for obtaining a screw rotor tooth form;

Figs. 6 and 7 show a second embodiment, in explanation of a process for obtaining a screw rotor tooth form;

Figs. 8 and 9 show a third embodiment, in explanation of a process for obtaining a screw rotor tooth form; and

Fig. 10 is a side view of the screw rotor showing a modification thereof.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A first embodiment of the screw rotor comprising a first embodiment of the invention will be described by referring to the drawings.

In Fig. 1, a female rotor 1 and a male rotor 2 are in meshing engagement with each other and rotate in the direction of arrows about center points 3 and 4 respectively within a casing, not shown, to enable the compressor to perform its function. 5 and 6 designate pitch circles of the two rotors 1 and 2. Assume that the female and male rotors 1 and 2 have basic tooth forms 7 and 8 respectively. The basic tooth forms 7 and 8 of the female and male rotors 1 and 2 are brought into meshing engagement with each other without any clearance therebetween in normal temperature condition (about 20°C at which the rotors are fabricated). The invention is not limited to any details of the shape and configuration of the basic tooth forms 7 and 8.

Figs. 2-4 shows a process in which the invention is worked. In this embodiment, the invention will be described as using the male rotor 2 as a reference and giving the basic tooth form 8 to the male rotor 2.

Referring to Figs. 2 and 3, the numeral 9 designates a rotor tooth form produced by deformation of the basic tooth form 8 on account of thermal expansion during operation of the rotors 1 and 2. The rotor tooth form 9 is obtained by calculation by a process of finite elements or the like based on a temperature distribution obtained by measuring the temperatures inside the rotor 2. The numeral 10 designates a rotor tooth form of the female rotor 1 generated by using the rotor tooth form 9. The rotor tooth form 10 is obtained from the rotor tooth form 9 which is a thermally deformed version of the basic rotor tooth form 8.

A rotor tooth form 11 of the female rotor 1 in normal temperature condition is obtained by converting the rotor tooth form 10 to a rotor tooth form of normal temperature condition. At this time, one has only to obtain the rotor tooth form 11 in normal temperature condition by a process of finite elements or the like based on a temperature distribution inside the female rotor 1, as the rotor tooth form 9 has been obtained.

A concrete example of the aforesaid process will be described by referring to a most simple case.

Assume that the temperature distribution in a cross section perpendicular to the axes of the two rotors 1 and 2 during operation is constant both inside and outside the rotors, and that the thermal expansion of the rotors caused by a rise in temperature occurs radially of the rotor in an amount corresponding to the distance between the center of each rotor and an arbitrarily selected point of the rotor tooth form.

Referreing to Fig. 4, the arbitrarily selected point 12 of the basic tooth form 8 of the male rotor 2 has a normal 12-13 perpendicular thereto. Expansion of the rotor tooth form 8 on account of a temperature rise causes the point 12 to shift to a point 14. At this time, the normal 14-15 perpendicular to the point 14 moves in parallel to the normal 12-13 and the point 14 exists on the rotor tooth form 9 produced by deformation of the rotor tooth form 8.

The rotor tooth form 9 is obtained by calculating the amounts of thermal expansion taking place in various points of the basic tooth form 8.

In obtaining the rotor tooth form 10 of the female rotor 1 generated by the rotor tooth form 9 of the male rotor 2 deformed by thermal expansion, a point 16 of the opposite rotor tooth form generated by the point 14 is obtained when the point 15 is located at the pitch point as shown in Fig. 5. The point 16 exists on the rotor tooth form 10.

For converting the rotor tooth form to the rotor tooth form 11, one has only to follow the process for converting the rotor tooth form 8 to the rotor tooth form 9 in reverse.

By generating the other rotor tooth form by using one rotor tooth form while taking thermal expansion into consideration, it is possible to maintain the clearance between the female rotor 1 and the male rotor 2 during operation to a minimum through the entire range in which the female and male rotors 1 and 2 mesh with each other. Thus the screw rotor of the dry type screw compressor can achieve marked improvement in performance as compared with the screw rotor of the oil-cooled type screw compressor.

Fig. 6 shows a second embodiment distinct in process from the first embodiment. In the figure, parts similar to those shown in Figs. 1-5 are designated by like reference characters.

Referring to Fig. 6, transmission of rotation between the female rotor 1 and the male rotor 2 is effected through synchronizing means, such as synchronizing gears, not shown, located outside working chambers of the two rotors 1 and 2. In this embodiment, the male rotor 2 is used as a reference and the basic tooth form 8 is given to the male rotor 2.

The numeral 17 designates a rotor tooth form obtained by reducing from the rotor tooth form 10 of the female rotor 1 an amount corresponding to the backlash of the synchronizing gear and the minimum clearance between the rotors 1 and 2 necessary for avoiding contact between the rotors 1 and 2 while they are in meshing with each other for rotation. The numeral 18 designates a rotor tooth form obtained by converting the rotor tooth form 17 to a rotor tooth form of normal temperature condition. The rotor tooth form 18 can also be obtained by a process of finite elements or the like based on a temperature distribution inside the female rotor 1.

The process for obtaining the rotor tooth form 17 will be desribed by referring to Fig. 7.

Referring to Fig. 7, let the sum of the backlash of the synchronizing gear on the pitch circle 5 of the female rotor 1 and the necessary minimum clearance between the two rotors 1 and 2, a length 3-19 of the radius vector at an arbitrarily selected point 19 of the rotor tooth form 10 deformed by thermal expansion, an angle formed by the radius vector and the normal perpendicular to the tooth form at the point 19, and a radius from the center 3 to the pitch circle 5 be denoted by C_o, R, α and R_p respectively. Then the point 19 arbitrarily selected on the rotor tooth form 10 becomes a point 20 when the backlash is taken into consideration. The distance between the two points 19 and 20 is denoted by C that can be expressed by the following formula:

$$C = \frac{R}{R_p} \cdot C_o \cdot \sin \alpha$$

The rotor tooth form 17 which takes the backlash into consideration can be obtained from the rotor tooth form 10 deformred by thermal expansion based on this formula.

In converting the rotor tooth form 17 to the rotor tooth form 18, one has only to follow the aforesaid process for converting the rotor tooth form 8 to the rotor tooth form 9 in reverse.

The reason why the backlash is taken into consideration is as follows: If synchronizing gears are used as synchronizing means, better effects can be achieved in operation by taking into consideration the backlash which is inevitable when the synchronizing gears operate, to obtain optimum meshing.

By taking into consideration the backlash of the synchronizing gears for the female and male rotors 1 and 2 deformed by thermal expansion in operation, it is possible to avoid contacting of the two rotors during operation, thereby improving the reliability of the screw compressor. The performance of the screw compressor can, of course, be improved by minimizing the backlash that is taken into consideration in the allowable range of values.

Fig. 8 and 9 show a third embodiment which is distinct from the first and second embodiments shown and described hereinabove in process. In the figures, parts similar to those shown in Figs. 1-7 are designated by like reference characters.

In the third embodiment, the male rotor is used as a reference and the basic tooth form 8 is given to the male rotor 2, as is the case with the first and second embodiments.

The numeral 21 designates a rotor tooth form that takes the backlash and thermal expansion into consideration. The rotor tooth form 21 is composed of the rotor tooth form 9 produced by deformation of the basic tooth form 8 on account of thermal expansion to which are added the backlash of the synchronizing gear and the necessary minimum clearance to avoid contacting of the rotors 1 and 2 in the process of meshing with each other. The numeral 22 designates a rotor tooth form of the female rotor 1 generated by using the rotor tooth form 21 by taking into consideration the thermal expansion of the male rotor 2 and the backlash of the synchronizing gear. The numeral 23 designates a rotor tooth form of the female rotor 1 obtained by converting the rotor tooth form 22 to a rotor tooth form in normal temperature condition.

By deciding the shape of the female rotor 1 and the male rotor 2 in this way, no more clearance than is necessary to provide for the backlash of the synchronizing gears and prevent the rotors 1 and 2 from coming into contact with each other during operation is provided to the two rotors 1 and 2, so that gas leaks can be minimized and the efficiency of the screw compressor can be greatly increased.

The clearance between the rotors and the casing can be set at a minimum value because the amount of deformation of the rotors on account of thermal deformation can be clearly defined.

In the first, second and third embodiments of the invention, the axial temperature distribution both inside and outside the rotors during operation is kept constant. However, a substantial temperature gradient may exist axially of each rotor depending on the type of working fluid, pressure conditions and other operation conditions. When a temperature distribution on the suction side of low temperature and a temperature distribution on the discharge side of high temperatuare are taken into consideration, the rotor tooth form may be tapered in such a manner that its outer periphery decreases in going from the suction side toward the discharge side.

More specifically, as shown in Fig. 10, the rotor tooth form is tapering in such a manner that its outer periphery convergingly tapers in going from one end on the suction side (indicated at A) to the other end on the discharge side (indicated at B).

Either one of the female and male rotors 1 and 2 or both of them may be tapering.

From the foregoing description, it will be appreciated that in the screw rotor according to the invention, the rotor tooth form of one of a female rotor and a male rotor meshing with each other without any clearance between them in normal temperature condition is used as a basic tooth form for obtaining a rotor tooth form produced by deformation on account of thermal expansion during operation; the rotor tooth form thus obtained is used for generating another rotor tooth form; and the rotor tooth form thus generated is used to obtain a rotor tooth form which is a normal temperature version of the thermally deformed tooth form, to thereby use the rotor tooth form of the normal temperature version for the other of the female and male rotors. By virtue of this feature, it is possible to maintain a minimum clearance between the female and male rotors through the entire region of the rotor tooth forms in which the female and male rotors mesh with each other, to thereby greatly increase the efficiency and performance of the screw compressor and improve the reliability thereof.

The second and third embodiments of the invention have been described as being applied to screw rotors of a screw compressor of the dry type. Needless to say, they can have application in screw rotors of a screw compressor of the oil-cooled type.

WHAT IS CLAIMED IS:

1. A screw rotor of a screw compressor comprising a female rotor and a male rotor rotating about two axes parallel to each other while in meshing engagement with each other, wherein the rotor tooth form of one of the female and male rotors meshing with each other without any clearance therebetween in normal temperatuer condition is used as a basic tooth form for obtaining a rotor tooth form produced by deformation on accoutn of thermal expansion during operation; the rotor tooth form thus obtained is used for generating another rotor tooth form; and the rotor tooth form thus generated is used to obtain a rotor tooth form which is a normal temperature version of the thermally deformed tooth form, to thereby use the rotor tooth form of the normal temperature version for the other of the female and male rotors.

2. A screw rotors as claimed in claim 1, wherein said female rotor and male rotor are shaped such that their outer periphery tapers in going from the lower pressure side toward the higher pressure side of the respective rotor.

3. A screw rotor as claimed in claim 1, wherein said female rotor is shaped such that its outer periphery tapers in going from the lower pressure side toward the higher pressure side of the rotor.

4. A screw rotor as cliamed in claim 1, wherein

said male rotor is shaped such that its outer periphery tapers in going from the lower pressure side toward the higher pressure side of the rotor.

5. A screw rotor of a screw compressor comprising a female rotor and a male rotor meshing but without coming into contact with each other for rotation about two parallel axes through synchronizing means, wherein the rotor tooth form of one of the female and male rotors meshing with each other without any clearance therebetween in normal temperature condition is used as a basic tooth form for obtaining a rotor tooth form produced by deformation on account of thermal expansion during operation; the rotor tooth form thus obtained is used for generating another tooth form; the rotor tooth form thus generated is used to obtain a rotor tooth form by reducing an amount corresponding to the backlash of the synchronizing means; and the rotor tooth form thus obtained is used to obtian a rotor tooth form which is a normal temperature version of the thermally deformed tooth form, to thereby use the rotor tooth form of the normal temperature version for the other of the female and male rotors.

6. A screw rotor as claimed in claim 5, wherein said female rotor and male rotor are shaped such that their outer periphery tapers in going from the lower pressure side toward the higher pressure side of the respective rotor.

7. A screw rotor as claimed in claim 5, wherein said female rotor is shaped such that its outer periphery tapers in going from the lower pressure side toward the higher pressure side of the rotor.

8. A screw rotor as claimed in claim 5, wherein said male rotor is shaped such that its outer periphery tapers in going from the lower pressure side toward the higher pressure side of the rotor.

9. A screw rotor of a screw compressor comprising a female rotor and a male rotor meshing but without coming into contact with each other for rotation about two parallel axes through synchronizing means, wherein the rotor tooth form of one of the female and male rotors meshing with each other without any clearance therebetween in normal temperature condition is used as a basic tooth form for obtaining a rotor tooth form produced by deformation on account of thermal expansion during operation; another tooth form is obtained by adding to the rotor tooth form thus obtained amounts corresponding to thermal expansion and backlash of the synchronizing means occurring during operation; the rotor tooth form thus obtained is used to generate another rotor tooth form; and the rotor tooth form thus obtained is used to obtain a rotor tooth form which is a normal temperature version of the thermally deformed tooth form, to thereby use the rotor tooth form of the normal temperature version for the other of the female and male rotors.

10. A screw rotor as claimed in claim 9, wherein said female rotor and male rotor are shaped such that their outer periphery tapers in going from the lower pressure side toward the higher pressure side of the respective rotor.

11. A screw rotor as claimed in claim 9, wherein said female rotor is shaped such that its outer periphery tapers in going from the lower pressure side toward the higher pressure side of the rotor.

12. A screw rotor as claimed in claim 9, wherein said male rotor is shaped such that its outer periphery tapers in going from the lower pressure side toward the higher pressure side of the rotor.

FIG. 1

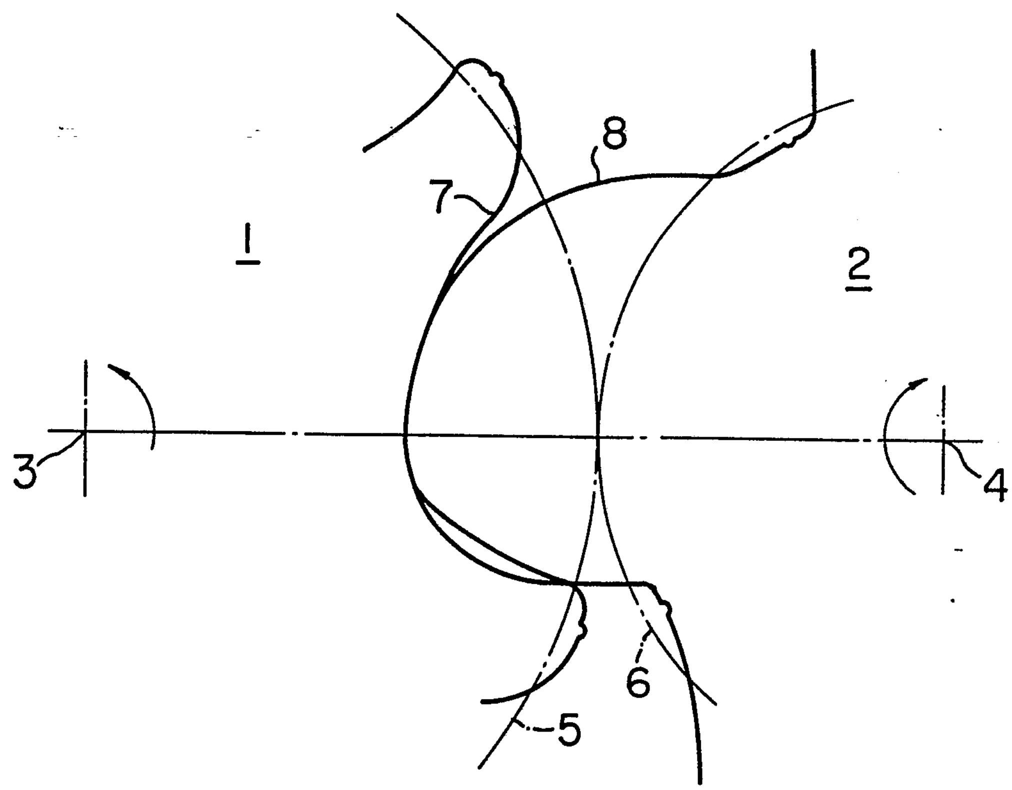


FIG. 2

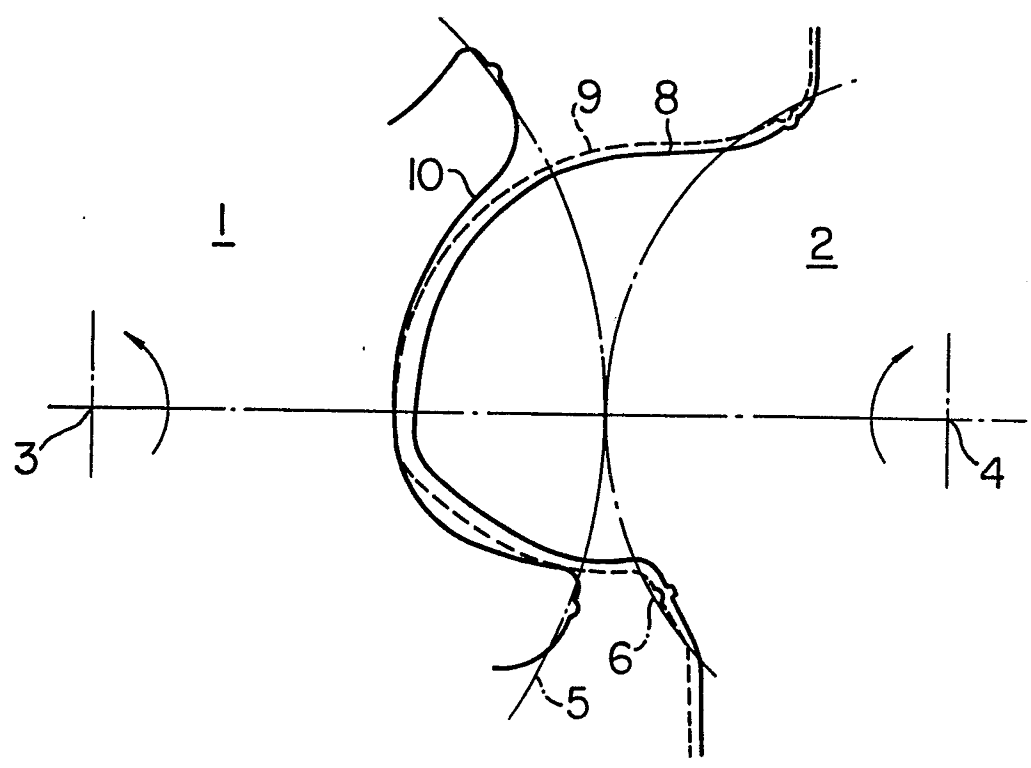


FIG. 3

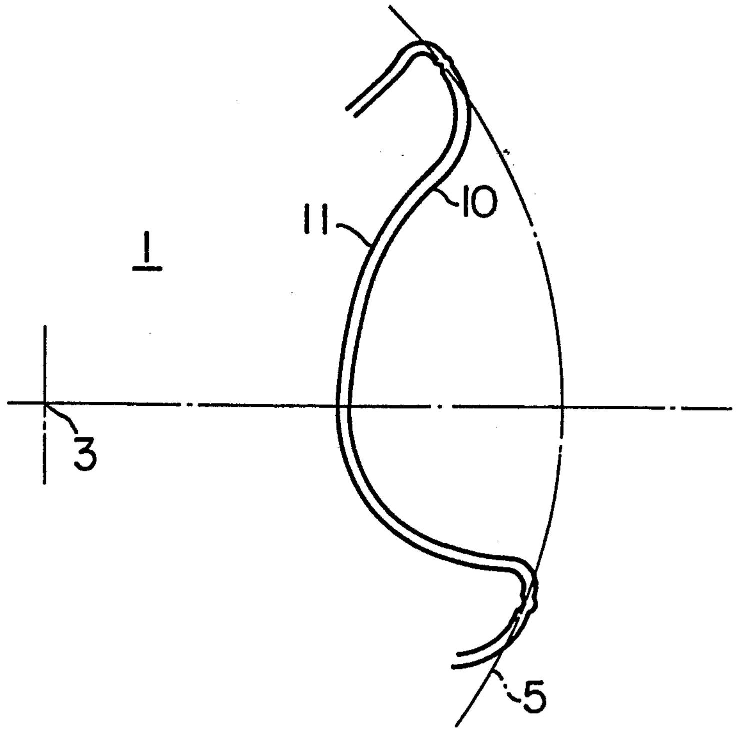


FIG. 4

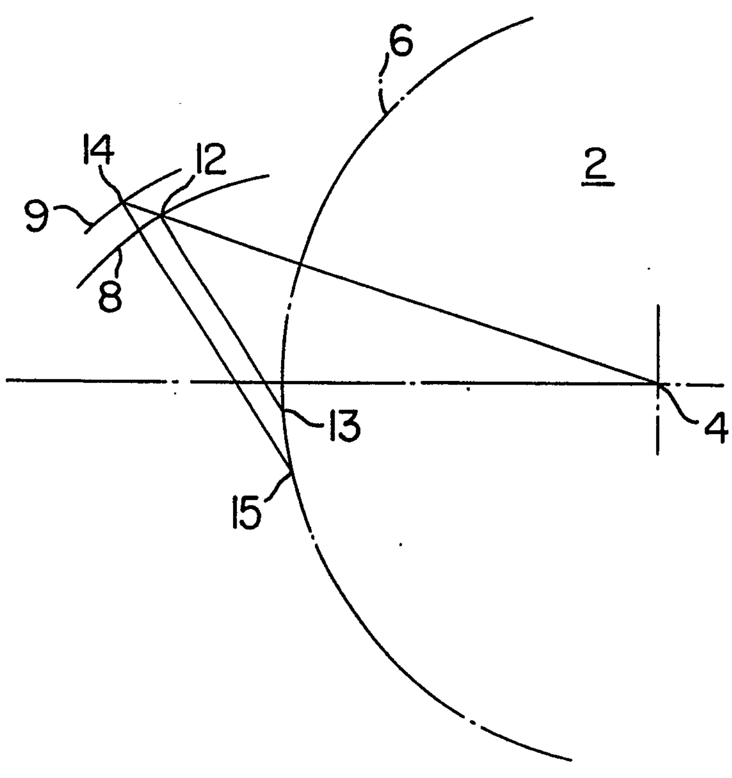


FIG. 5

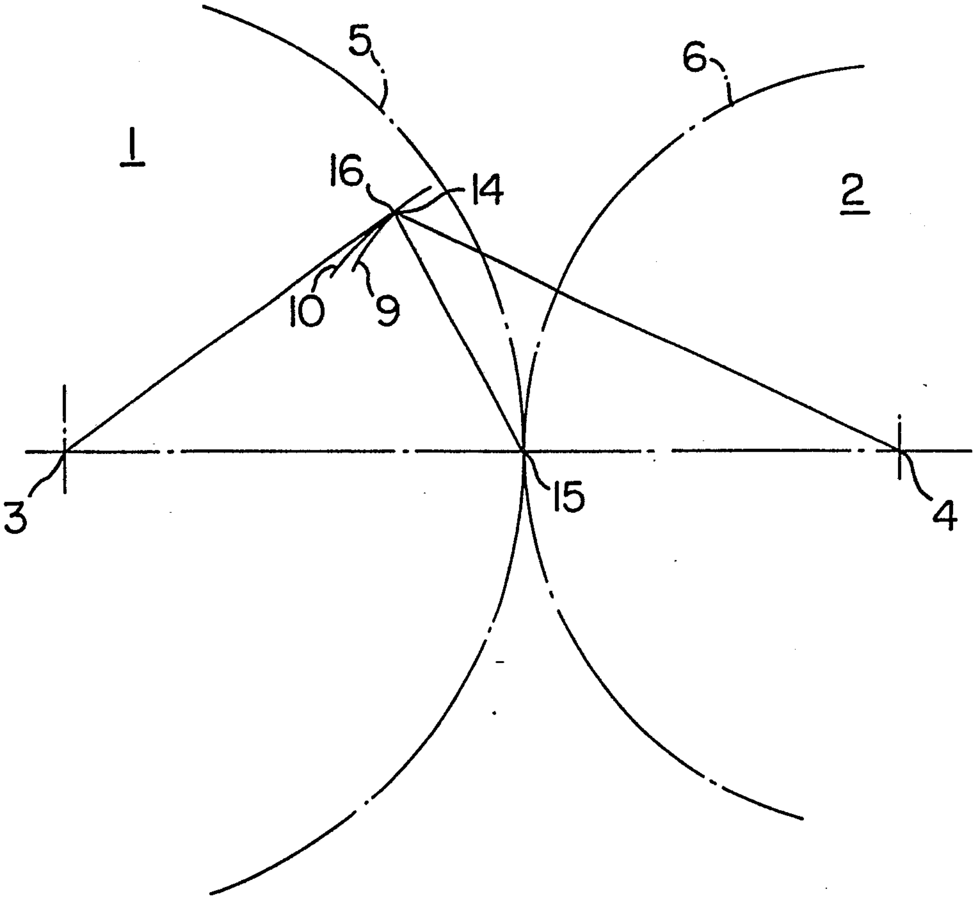


FIG. 6

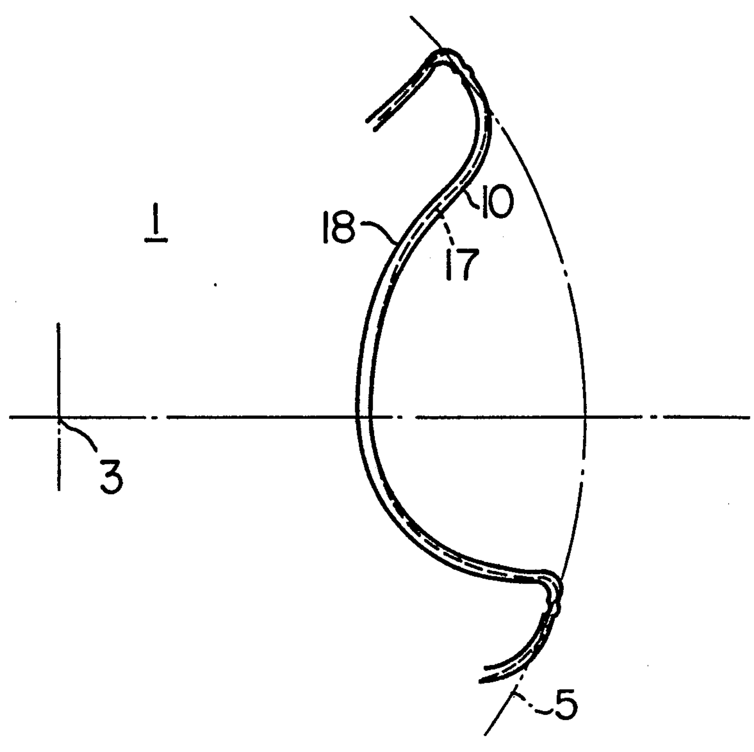


FIG. 7

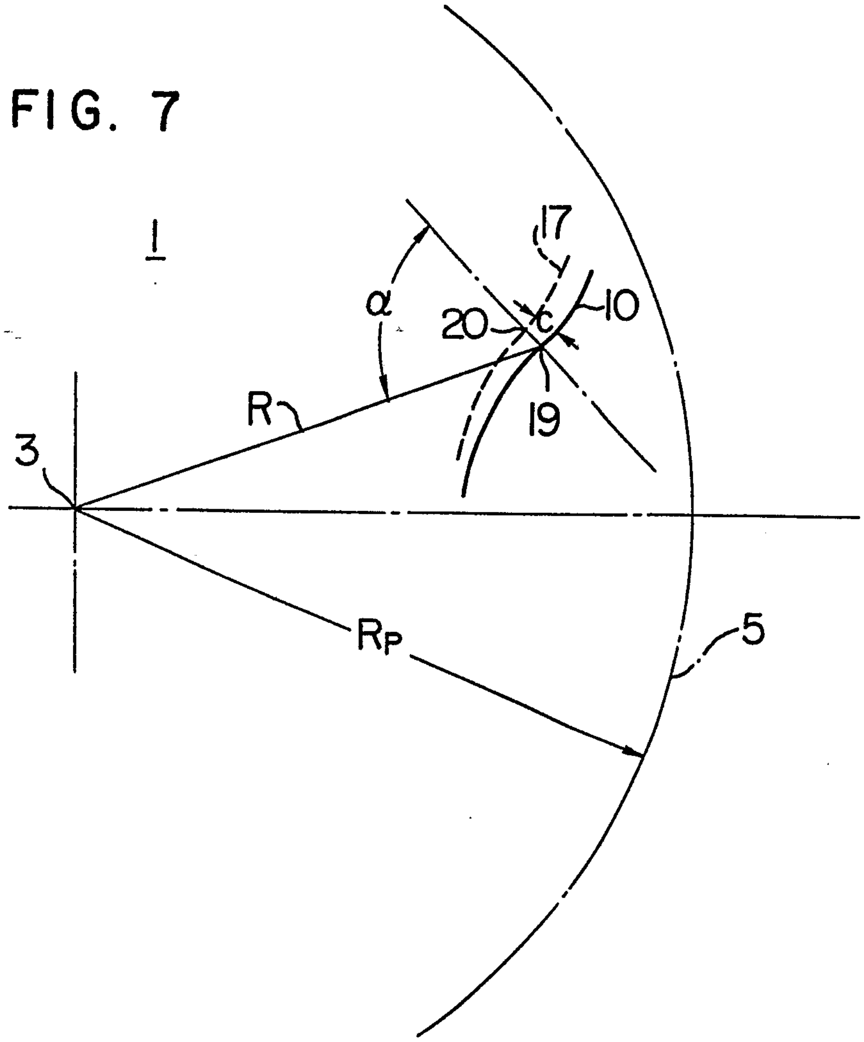


FIG. 8

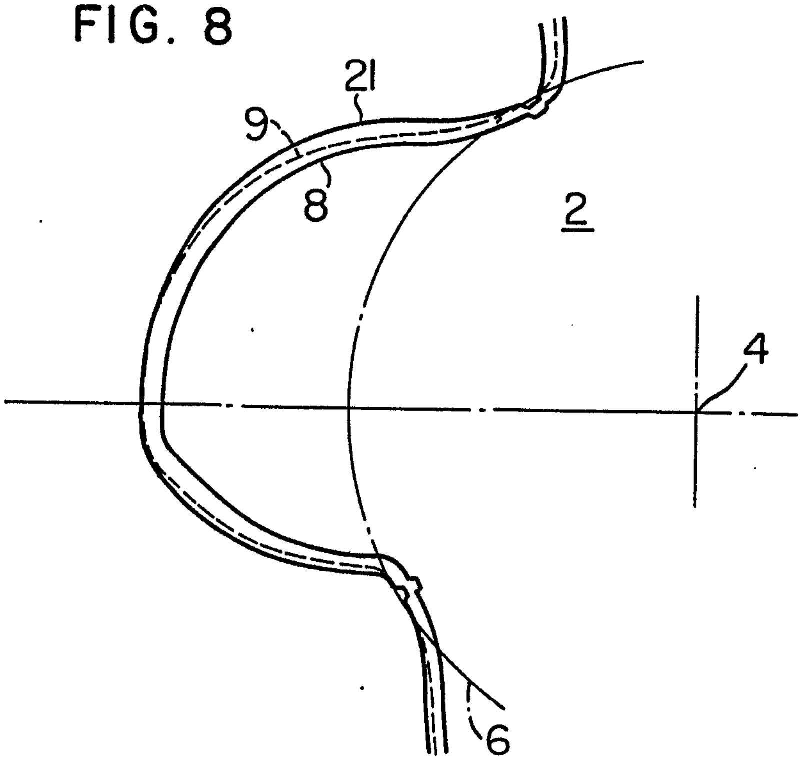


FIG. 9

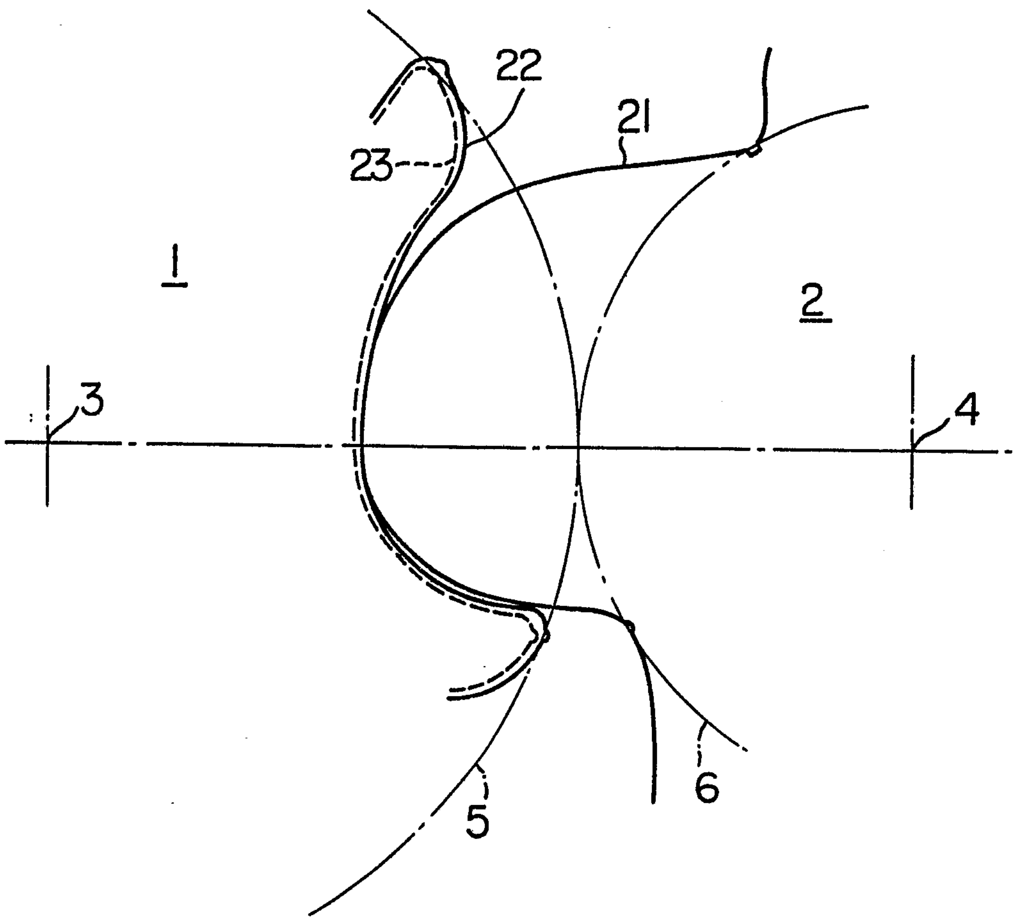
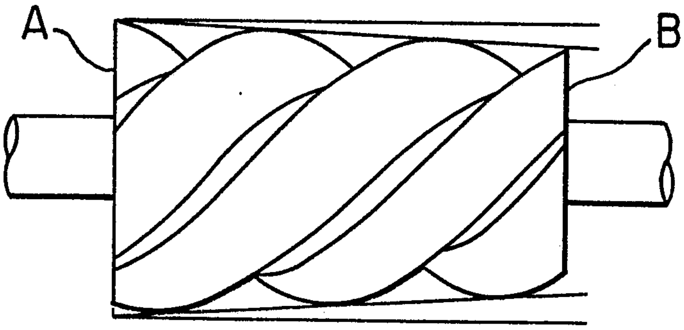


FIG. 10



European Patent Office

EUROPEAN SEARCH REPORT

0104265

Application number

EP 82 10 8865

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. 3)
A	US-A-4 140 445 (SCHIBBYE) * Column 4, line 66 - column 5, line 63; figure 3 *	1,5,9	F 04 C 18/16

A	US-A-3 787 154 (EDSTROM) * Column 6, line 33 - column 7, line 40; figure 4 *	1	

A	FR-A-2 253 930 (DEMAG) * Page 1; page 2, lines 1-9; pages 4,5; figures *	2-4,6-7,10-12	

A	DE-A-1 403 534 (HOWDEN & CO.) * Page 3; page 6, last paragraph; pages 7-9; figures *	2-4,6-8,10-12	TECHNICAL FIELDS SEARCHED (Int. Cl. 3)
	-----		F 01 C F 04 C

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	19-05-1983	KAPOULAS T.

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

EPO Form 1503. 03.82