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(54) MESHING SCREW ROTARY POSITIVE-DISPLACEMENT MACHINE

(71) We, HOKUETSU KOGYO COMPANY LIMITED, a Japanese Corporation, of No. 113-1 Ohtakeshinden, Oaza, Bunsui-Cho, Nishikanbara-gun, Niigata-ken, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a meshing-screw rotary positive-displacement machine, such as a compressor or an expander, of the type which comprises a cylinder with end walls, a pair of parallel, mutually intersecting bores in said cylinder, and male and female screw rotors housed in said bores and being mutually engaged, the arrangement being such that, in use, rotation of both rotors changes the volumes of chambers defined by the walls of said bores, the end walls, and the threads of both rotors. Such a machine will henceforth be referred to as a machine of the type specified.

In a machine of the type specified, the power efficiency mainly depends on the fluid tightness between adjacent ones of the compressing or expanding chambers. That is, the less the leak of gas between adjacent chambers, the higher the volumetric efficiency and the higher the total adiabatic efficiency.

The greatest problem in lessening the gas leak between adjacent chambers is the gas tightness between the engaging surface of the male and female rotors.

A fairly good gas tightness may be obtained by decreasing the gap dimensionally by providing sealing strips between the outer surfaces of the rotors and the inner surface of the cylinder or between the end faces of the rotors and the end wall surfaces of the cylinder, or particularly in an oil cooling type by enhancing the sealing by means of lubricant. If the line of contact between the male and female rotors which separates the adjacent chambers i.e. the compressing side and suction side is the locus of rolling contact or sliding contact between the top and bottom of the male and female rotors, it is

relatively easy to seal the compressing or expanding chambers along this locus of contact with fair accuracy.

It is not easy, however, to produce gas tightness between adjacent compressing or expanding chambers along the threads of the male and female rotors and the line of intersection between the inner surface of the cylinder portion housing the male rotor and the inner surface of the cylinder portion housing the female rotor. Still this is a very important problem.

Conventional theory of thread profile in screw type rotary machines has developed about the problem of friction power due to the rolling or sliding contact of the engaging threads of the male and female rotors or the problem of sealing quality on account of the length of the line of contact of the male and female rotors. Such theory has taught that a shorter line of contact between the male and female rotors is better and a continuous curve without any bend is desirable.

The present invention involves a theory, different from the conventional theory, in which, even though the line of contact between the male and female rotors is long and is bent discontinuously, the line is extended to the intersecting line on the closing side between the inner surface of the cylinder portion housing the male rotor and the inner surface of the cylinder portion housing the female rotor, whereby eliminating short cut or leaking space between adjacent compressing or expanding chambers.

An object of the invention is to provide a meshing-screw rotary positive-displacement machine of the type specified, such as a compressor or expander, which has good gas tightness between the engaging surfaces of the male and female rotors, which eliminates gas leakage between adjacent compressing or expanding chambers, and which minimizes the containment pockets between the rotors, thereby achieving greater power efficiency.

According to the present invention, there is provided a meshing-screw rotary positive-displacement machine of the type specified,

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wherein the cross-sectional profile of each thread of the male rotor comprises a crest defined by a circular arc having a substantial length and extending from a leading side of the thread to a trailing side thereof, said circular arc having its centre of curvature on the axis of rotation of the male rotor and being of a constant radius; said leading side having a root portion and a further portion extending from said root portion to said crest, said root portion being defined by a line generated by a point at the trailing edge of a crest of a thread of the female rotor, said further portion being arranged to create a minimum containment pocket between itself and the threads of the female rotor when it passes between the latter in use; said trailing side being defined by a line generated by a point at the leading end of a crest of a thread of the female rotor and extending from the trailing end of said crest to a root point, said crest and said trailing side meeting at an apex; the cross-sectional profile of each thread of the female rotor comprising a crest; a leading side defined by a line generated by the said apex on a thread of the male rotor, said leading side extending between a root point and a leading end of said crest, said crest and said leading side meeting at a sharp apex; and a trailing side defined by a line which is the envelope of the said further portion of a leading side of a thread of the male rotor; the arrangement being such that, at the moment when both rotors close in use, the said apex on a thread of the male rotor, the said sharp apex on a thread of the female rotor, and a point on a line of intersection of said bores met simultaneously so as to eliminate leakage between said chamber, the line of contact between said male and female rotors thereby extending to the intersection line on the closing side of said bores.

Preferably, a first sealing strip is provided at the said apex of each thread of the male rotor; and a second sealing strip is provided at the said sharp apex of each thread of the female rotor, the arrangement being such that as soon as the said apex on a thread of the male rotor leaves the line of intersection of said bores in use, the said apex on a thread of the female rotor proceeds in contact with the trailing side of the thread of the male rotor so as to eliminate leakage between said chambers, the threads of the female rotor and the threads of the male rotor thereby contacting continuously.

Embodiments of the present invention will now be described in detail with reference to the accompanying drawings, in which

Figure 1 is a transverse cross section of a known meshing-screw rotary positive-displacement machine,

Figure 2 is a similar cross section of the rotary machine in Figure 1, showing the

position of the male and female rotors after they have rotated a little in the direction of the arrow from the position shown in Figure 1,

Figure 3 is a longitudinal cross section of a meshing-screw rotary positive-displacement machine according to the present invention,

Figure 4 is a transverse cross section of the machine shown in Figure 3,

Figure 5 is an enlarged view of part of Figure 4,

Figures 6 and 7 are similar views to Figure 5 and show the position of the male and female rotors after they have rotated progressively from the position shown in Figure 5 in the direction of the arrow,

Figure 8 is a side view of the male rotor, showing the line of contact between the rotors,

Figure 9 is a side view of a conventional male rotor showing its line of contact with the female rotor,

Figure 10 is a transverse cross section of a part of the rotary machine of Figures 3 to 8, provided with a conventional sealing strip,

Figure 11 is a transverse cross section of a part of an alternative embodiment of the meshing-screw rotary positive-displacement machine of the present invention, and

Figure 12 is a similar view showing the position of the male and female rotors after having rotated from the position shown in Figure 12 in the direction of the arrow.

Referring to Figures 1 and 2, there is shown a known rotary air compressor of the meshing-screw type having a male screw rotor 1 with four helical teeth or threads 2 and a female screw rotor 3 with six helical teeth or threads 4. A cylinder 5 has inner surfaces 6 and 7 defining parallel, mutually-intersecting bores which house the male and female rotors 1 and 3 respectively in mutually meshing relation. The inner surfaces 6 and 7 are connected at intersection lines 8 and 8'. Chambers or spaces 9 or 9' are formed between adjacent threads on the male and female rotors.

When the rotors 1 and 3 are rotated in the direction of the arrows, and one of the threads 2 of the male rotor 1 enters a chamber between the threads 4 of the female rotor 3, air in that chamber becomes compressed. This chamber, denoted by 9' in Figure 1, is therefore a compressing chamber. When the rotors 1 and 3 occupy the position shown in Figure 2 after having rotated a little from the position shown in Figure 1 in the direction of the arrow, a leading end 10 of a crest of a thread 4 of the female rotor 3 has reached the intersection line 8 on the closing side of the bores, but a crest 11 of a thread 2 of the male rotor 1 has gone past the intersection line 8 and is largely ahead thereof. Thus, the compressing chamber 9' is short

circuited to the next chamber 9 because of the formation of a gap between the crest 11, the intersection line 8 and the end 10. This short circuiting occurs not only at the suction stage, but also during compression, and this produces leakage and reverse flow of the compressed gas. Such leakage and reverse flow lowers the volumetric efficiency and total adiabatic efficiency of the rotary machine.

Referring now to Figures 3 to 8, there is shown a first embodiment of the meshing-screw rotary positive-displacement machine of the present invention. A cylinder 5 with end walls 34 and 34' has inner surfaces 6 and 7 which define a pair of parallel, mutually-intersecting bores. In these bores are housed respectively a male screw rotor 12 having four threads 13 and a female screw rotor 14 having six threads 15, the rotors 12 and 14 being mutually engaged. The inner surfaces 6 and 7 are connected at intersection lines 8 and 8'.

Referring more particularly to Figure 5, the cross sectional profile of each thread 13 of the male rotor 12 includes a crest which is defined by a circular arc having a substantial length α and extending from a leading side 20 of the thread 13 to a trailing side 32 thereof. The circular arc has its centre of curvature on the axis of rotation O of the male rotor 12, and is of a constant radius R. This radius is equal to the maximum radius of the thread of a conventional male rotor. The leading side 20 has a root portion 23 and a further portion 23a extending from the root portion 23 to the crest. The root portion 23 is defined by a line generated by a point at a trailing end 22 of a crest of a thread 15 of the female rotor 14. The further portion 23a is arranged so that, when the thread 13 passes between the threads 15 of the female rotor 14, it creates a minimum containment pocket or residual space 24 therebetween.

The trailing side 32 of each thread 13 is defined by a line generated by a point at the leading end 16 of a crest of a thread 15 of the female rotor 14. The trailing side 32 extends from a trailing end 17 of the crest of the male rotor thread 13 to a root point 18, and the crest and the trailing side 32 meet at an apex at the end 17 of the latter.

The cross sectional profile of each thread 15 of the female rotor 14 comprises a crest, a leading side 33 and a trailing side 21. The leading side 33 is defined by a line generated by the apex 17 on a thread 13 of the male rotor 12, and extends between a root point 19 and a leading end 16 of the crest. The crest and the leading side 33 meet at a sharp apex at the end 16 of the latter. The trailing side 21 is defined by a line which is the envelope of the further portion 23a of a

leading side 20 of a thread 13 of the male rotor 12.

The above-described machine operates as follows. The rotors 12 and 14 are rotated in the direction shown by the arrows in Figure 5. It is to be appreciated that the broken line in this Figure shows the position of the male rotor 12 before it reaches the position shown by the full line. When the rotors 12 and 14 reach the position shown in Figure 6, the leading end 16 of the crest of a female rotor thread 15 reaches the intersection line 8 as soon as the trailing end 17 of the crest of a male rotor thread 13 passes the line 8. Thus, as soon as the end 17 leaves the intersection line 8, the apex at the end 17, the sharp apex at the end 16 and a point on the line 8 meet simultaneously, thereby enabling perfect closing. The apex at the end 16 may be formed so as to have a radius of curvature of less than 1.5 mm for the sake of safety in handling or for the sake of strength. If the apex at end 16 has a relatively large round form, this apex, the apex at end 17 on the male rotor thread 13 and the intersection line 18 cannot meet and contact together at one point simultaneously. Therefore, perfect closing between adjacent compressing or expanding chambers cannot be achieved.

On continued rotation of the rotors 12 and 14, the apex at end 16 on the female rotor thread 15 comes into contact with the trailing side 32 of the male rotor thread 13 and then slides along the trailing side 32. This serves to ensure gas tightness between the male rotor thread 13 and the inner surface 16 of the cylinder 5. The rotors 12 and 14 then move into their position of deepest engagement, as shown in Figure 7. In this position, one thread 13 of the male rotor 12 is just opposite the female rotor 14 on a line drawn between the rotation axes of both rotors, and there is virtually no containment pocket between root point 19 and a trailing end 22 of the crest of the female rotor thread 15. Also, the containment pocket or residual space 24 between both rotors is very small. In a compressor of the type in which a liquid, e.g. oil, is injected into the rotor chamber to perform cooling, lubrication and sealing, the above mentioned small residual space will be filled with the liquid and re-expansion losses will substantially not be incurred.

Referring now to Figure 8, the chain dotted line represents the intersection line 8 as shown in Figures 4, 5 and 6. The curve 17 is the trailing end of the crest of each male rotor thread 13, also as shown in Figures 4, 5 and 6. The broken line 25 indicates the line of contact between the male and female rotors, and it can be seen that this line of contact extends to and reaches the intersection line 8 at the points 26. Thus,

it will be manifest that there is no short circuiting or leakage space between the compressing or expanding chambers near the intersection line 8, and that therefore the leakage space is theoretically zero.

Figure 9 illustrates a corresponding line of contact 27 for the conventional male rotor shown in Figures 1 and 2. It can be seen that the limits of extraction of this line, indicated at 28, do not extend to the intersection line 8 in an effort to obtain as short a line of contact as possible. Therefore, the leakage space is large, which results in decreased efficiency.

In Figure 10, the machine described above in relation to Figures 3 to 8 is shown provided with conventionally positioned sealing strips 29 and 30. These sealing strips 29 and 30 are provided on the crest of each of the threads 13 and 15 respectively, and grooves 31 are formed in the male rotor to receive the sealing strips 30 on the female rotor. In such an arrangement, the sealing strips 29 and 30 should be of a suitable height, say 0.5 to 1.0 mm, to avoid seizure when they contact with the inner surfaces 6 and 7 of the cylinder 5. This results in a gap d , which is more than the height of sealing strips themselves, between the general outer surface of the rotors and the inner surfaces 6 and 7 of the cylinder 5. In this case, even if the apex at the leading end 26 of the crest of a female rotor thread 15 and the apex at the trailing end 17 of the crest of a male rotor thread 13 meet together simultaneously at the position of the intersection line 8, there will be a large gap between the end 16 and the end 17, and therefore the trailing side 32 of the male rotor thread 13 will not engage continuously the leading side 33 of the female rotor thread 15. This results in a leakage in such discontinuous region.

As an alternative embodiment of the present invention is shown in Figures 11 and 12. In this embodiment, a sealing strip 29¹ is attached to the end 17 of the crest of each male rotor thread 13, and a sealing strip 30¹ is provided on the end 16 of the crest of each female rotor thread 15. The male rotor is also provided with a groove 31¹ for receiving each sealing strip 30¹.

When the rotors rotate from the position shown in Figure 11 to the position shown in Figure 12, at the moment that the end 17 of the crest of a male rotor thread 13 leaves the intersection line 8, the end 16 of the crest of a female rotor thread 15 is in contact with the end 17. It is to be pointed out that the leading side 33 of each female rotor thread 15 is so formed that it continuously contacts with the trailing side 32 of a male rotor thread 13. In this way, the discontinuous area in the example of Figure 10 is

eliminated, and hence there is no short circuit leakage.

WHAT WE CLAIM IS:—

1. A meshing-screw rotary positive-displacement machine, comprising a cylinder with end walls; a pair of parallel, mutually intersecting bores in said cylinder; and male and female screw rotors housed in said bores and being mutually engaged, the arrangement being such that, in use, rotation of both rotors changes the volumes of chambers defined by the walls of said bores, the end walls, and the threads of both rotors; the cross-sectional profile of each thread of the male rotor comprising

a crest defined by a circular arc having a substantial length and extending from a leading side of the thread to a trailing side thereof, said circular arc having its centre of curvature on the axis of rotation of the male rotor and being of a constant radius;

said leading side having a root portion and a further portion extending from said root portion to said crest, said root portion being defined by a line generated by a point at a trailing end of a crest of a thread of the female rotor, said further portion being arranged to create a minimum containment pocket between itself and the threads of the female rotor when it passes between the later in use;

said trailing side being defined by a line generated by a point at a leading end of a crest of a thread of the female rotor and extending from a trailing end of said crest of the male rotor thread to a root point, said crest and said trailing side meeting at an apex;

the cross-sectional profile of each thread of the female rotor comprising

a crest;

a leading side defined by a line generated by the said apex on a thread of the male rotor, said leading side extending between a root point and a leading end of said crest, said crest and said leading side meeting at a sharp apex; and

a trailing side defined by a line which is the envelope of the said further portion of a leading side of a thread of the male rotor;

the arrangement being such that, at the moment when both rotors close in use, the said apex on a thread of the male rotor, the said sharp apex on a thread of the female rotor, and a point on a line of intersection of said bores meet simultaneously so as to eliminate leakage between said chambers, the line of contact between said male and female rotors thereby extending to the intersection line on the closing side of said bores.

2. A machine as claimed in claim 1, wherein a first sealing strip is provided at the said apex of each thread of the male rotor, and a second sealing strip is pro-

it will be manifest that there is no short circuiting or leakage space between the compressing or expanding chambers near the intersection line 8, and that therefore the leakage space is theoretically zero.

Figure 9 illustrates a corresponding line of contact 27 for the conventional male rotor shown in Figures 1 and 2. It can be seen that the limits of extraction of this line, indicated at 28, do not extend to the intersection line 8 in an effort to obtain as short a line of contact as possible. Therefore, the leakage space is large, which results in decreased efficiency.

In Figure 10, the machine described above in relation to Figures 3 to 8 is shown provided with conventionally positioned sealing strips 29 and 30. These sealing strips 29 and 30 are provided on the crest of each of the threads 13 and 15 respectively, and grooves 31 are formed in the male rotor to receive the sealing strips 30 on the female rotor. In such an arrangement, the sealing strips 29 and 30 should be of a suitable height, say 0.5 to 1.0 mm, to avoid seizure when they contact with the inner surfaces 6 and 7 of the cylinder 5. This results in a gap d , which is more than the height of sealing strips themselves, between the general outer surface of the rotors and the inner surfaces 6 and 7 of the cylinder 5. In this case, even if the apex at the leading end 26 of the crest of a female rotor thread 15 and the apex at the trailing end 17 of the crest of a male rotor thread 13 meet together simultaneously at the position of the intersection line 8, there will be a large gap between the end 16 and the end 17, and therefore the trailing side 32 of the male rotor thread 13 will not engage continuously the leading side 33 of the female rotor thread 15. This results in a leakage in such discontinuous region.

As an alternative embodiment of the present invention is shown in Figures 11 and 12. In this embodiment, a sealing strip 29¹ is attached to the end 17 of the crest of each male rotor thread 13, and a sealing strip 30¹ is provided on the end 16 of the crest of each female rotor thread 15. The male rotor is also provided with a groove 31¹ for receiving each sealing strip 30¹.

When the rotors rotate from the position shown in Figure 11 to the position shown in Figure 12, at the moment that the end 17 of the crest of a male rotor thread 13 leaves the intersection line 8, the end 16 of the crest of a female rotor thread 15 is in contact with the end 17. It is to be pointed out that the leading side 33 of each female rotor thread 15 is so formed that it continuously contacts with the trailing side 32 of a male rotor thread 13. In this way, the discontinuous area in the example of Figure 10 is

eliminated, and hence there is no short circuit leakage.

WHAT WE CLAIM IS:—

1. A meshing-screw rotary positive-displacement machine, comprising a cylinder with end walls; a pair of parallel, mutually intersecting bores in said cylinder; and male and female screw rotors housed in said bores and being mutually engaged, the arrangement being such that, in use, rotation of both rotors changes the volumes of chambers defined by the walls of said bores, the end walls, and the threads of both rotors; the cross-sectional profile of each thread of the male rotor comprising

a crest defined by a circular arc having a substantial length and extending from a leading side of the thread to a trailing side thereof, said circular arc having its centre of curvature on the axis of rotation of the male rotor and being of a constant radius;

said leading side having a root portion and a further portion extending from said root portion to said crest, said root portion being defined by a line generated by a point at a trailing end of a crest of a thread of the female rotor, said further portion being arranged to create a minimum containment pocket between itself and the threads of the female rotor when it passes between the later in use;

said trailing side being defined by a line generated by a point at a leading end of a crest of a thread of the female rotor and extending from a trailing end of said crest of the male rotor thread to a root point, said crest and said trailing side meeting at an apex;

the cross-sectional profile of each thread of the female rotor comprising

a crest;
a leading side defined by a line generated by the said apex on a thread of the male rotor, said leading side extending between a root point and a leading end of said crest, said crest and said leading side meeting at a sharp apex; and

a trailing side defined by a line which is the envelope of the said further portion of a leading side of a thread of the male rotor;

the arrangement being such that, at the moment when both rotors close in use, the said apex on a thread of the male rotor, the said sharp apex on a thread of the female rotor, and a point on a line of intersection of said bores meet simultaneously so as to eliminate leakage between said chambers, the line of contact between said male and female rotors thereby extending to the intersection line on the closing side of said bores.

2. A machine as claimed in claim 1, wherein a first sealing strip is provided at the said apex of each thread of the male rotor, and a second sealing strip is pro-



vided at the said sharp apex of each thread of the female rotor, the arrangement being such that as soon as the said apex on a thread of the male rotor leaves the line of intersection of said bores in use, the said apex on a thread of the female rotor proceeds in contact with the trailing side of the thread of the male rotor so as to eliminate leakage

between said chambers, the threads of the female rotor and the threads of the male rotor thereby contacting continuously. 10

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