

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
13 January 2011 (13.01.2011)

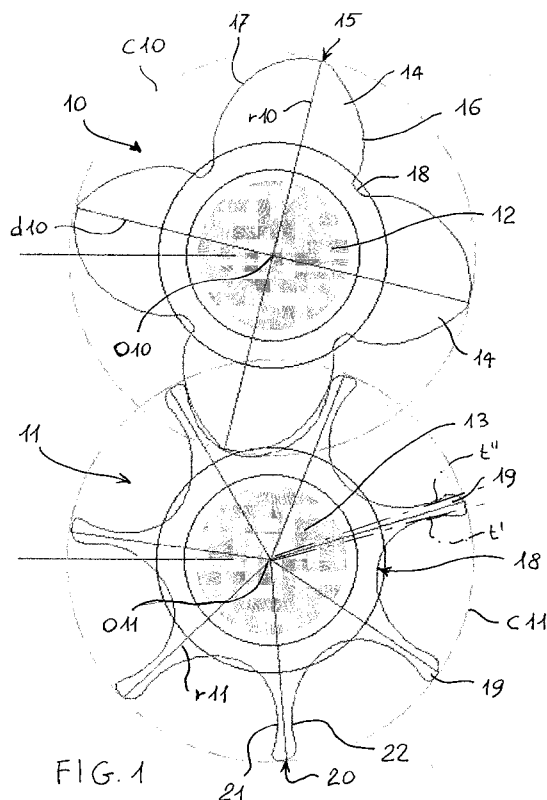
PCT

(10) International Publication Number
WO 2011/004342 A2

- (51) International Patent Classification:
F04C 18/08 (2006.01) *F01C 1/08* (2006.01)
- (74) Agent: **PROVVISIONATO, Paolo**; c/o Provvisionato & Co S.r.l., Piazza di Porta Mascarella, 7, I-40126 Bologna (BO) (IT).
- (21) International Application Number:
PCT/IB2010/053135
- (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (22) International Filing Date:
8 July 2010 (08.07.2010)
- (25) Filing Language:
Italian
- (26) Publication Language:
English
- (30) Priority Data:
BO2009A000442 9 July 2009 (09.07.2009) IT
- (71) Applicant (for all designated States except US): **BORA S.r.l.** [IT/IT]; Via dei Carpentieri, 15, I-41100 Modena (IT).
- (84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK,
- (72) Inventor; and
- (75) Inventor/Applicant (for US only): **MORSELLI, Mario Antonio** [IT/IT]; Via del Carmine, 23, I-41100 Modena (IT).

[Continued on next page]

(54) Title: ROTORS FOR A ROTARY SCREW MACHINE



(57) Abstract: A rotary screw machine, such as a screw compressor, a vacuum pump or a motor, comprises mating rotors having asymmetrical profiles and the same outer diameter. Preferably, the end of the male rotor tooth has, from the point of maximum radius, on both flanks, two portions of arcs of a circle appreciably different in size as regards radius, but tangent, which describe a part of the left-hand flank and a part of the right-hand flank respectively. The female rotor has the respective matings in the corresponding area of the bottom of the tooth. Preferably the male rotor has three or four threads, while the female rotor preferably has six or seven threads, and even more preferably the male rotor has four threads and the female rotor has seven threads. From the centre of the female rotor lines can be drawn tangent to the two flanks of the same tooth.

WO 2011/004342 A2

SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG). **Published:**

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

ROTORS FOR A ROTARY SCREW MACHINE

The present invention relates to the rotary screw machine sector. A typical, although non-limiting, example of a rotary screw machine is the screw compressor. Rotary screw machines can also be used as vacuum pumps or as motors.

The invention has been developed with particular regard to mating rotors capable of rotating about parallel axes inside a working space within a rotary screw machine. The rotors have a series of threads that are wound in a helical manner with respect to the axis of rotation of the rotors and that have, in a transverse section relative to the axis of rotation, characteristic profiles. The profile of the threads of the screws formed on the two rotors is different for the two rotors. Typically, one of the two rotors has a profile with a series of generally convex ridges, each constituting a screw thread, which engage in corresponding generally concave grooves formed on the other rotor. For simplicity of description, we shall henceforth call the rotor whose screw threads have generally convex ridges the male rotor, while we shall call the rotor that has generally concave grooves, separated from each other by screw threads that are in the shape of thin ribs, the female rotor.

The most recent prior art has proposed various profiles of rotors with asymmetrical profiles, that is, in which one flank of the ridge, in the male rotor, or of the rib, in the female rotor, is not radially symmetrical in relation to the other flank, and with a different number of threads for the male rotor and the female rotor (generally, with the number of threads of the female rotor, that is – in section – the number of ribs, greater than the number of threads of the male rotor, that is – in section – the number of convex ridges).

The combination of asymmetrical profiles and different number of threads in the rotors of the most recent prior art, although useful for the purpose of efficiency of the profiles and therefore of the rotary screw machine, has various drawbacks as regards the machining required to produce the rotary screw machine, both as regards costs and precision. In fact, two different tools have to be used to ream the two housings of the rotors, which in turn involves stopping the machine to change tools. Apart from the purely financial loss of machine time, there is a technological disadvantage, linked to the fact that the tool change introduces a significant error for these extremely delicate machines that require great precision.

With the rotors of the prior art, assembling the rotary screw machine with centring in situ is complex and producing a machine that can operate both as a vacuum pump and as a

compressor is also complex because, in this case, it is necessary to change round the position of the bearings with axial constraint.

Document GB-A-1388376 shows a screw pump with two rotors having asymmetrical profiles and the same outer diameter. The profiles of the rotors illustrated in this document are, however, rather rough and decidedly inefficient, because they have a poor seal on mating.

The research conducted by the present applicant has identified the mating between profiles as being one of the most critical aspects that prevent the machines of the prior art from achieving good performance. For example, the wide outer cylindrical portion, at the end of each female rotor tooth profile in the above-mentioned document GB-A-1388376, causes a very poor seal of the rotors during the operation of the screw machine, with a consequent drop in performance.

The object of the present invention is to overcome the drawbacks of the prior art by providing two mating rotors for a rotary screw machine that are efficient and have a good mating coupling and therefore a good seal.

Another object of the invention is to propose two mating rotors that can be mounted easily and simply in a rotary screw machine, that are simple and inexpensive to produce, and that are nevertheless highly efficient.

Another object of the invention is to provide two mating rotors that are simple and inexpensive to manufacture in order to produce a rotary screw machine that can operate both as a vacuum pump and as a compressor or motor without significant modifications being required.

In order to achieve the above-mentioned objects, the invention relates to two mating rotors defined in the claims below.

The invention relates also to a rotary screw machine using the above-mentioned rotors.

The rotors of the present invention preferably have a number of threads equal to three or four for the male rotor, and correspondingly equal to six or seven for the female rotor. This affords considerable advantages as regards machining and configuration favourable to filling by the fluid to be processed in the rotary screw machine.

Preferably, the two rotors with asymmetrical profiles according to the present invention can be manufactured so as to have a nominally identical outer diameter, for greater simplicity of machining.

According to another advantageous characteristic, the teeth of the female rotor have an end area that is substantially free of sharp edges or very small radii of curvature, with the

consequent absence of excessively small concave radii of curvature in the male rotor, in areas that otherwise would be difficult to machine. Furthermore, this characteristic contributes to the general object of improving mating, with the resulting advantages as regards sealing.

According to another advantageous characteristic, the ends of the teeth of the female rotor have a completely or almost completely rounded shape, with the complete or almost complete elimination of the portion of outer cylindrical profile of the prior art. This results in better coupling on mating and therefore improves sealing and also presents less of an obstacle to filling.

Advantageously, the profile of the female rotor teeth is "finger-shaped" with a clear narrowing in a substantially intermediate area between the end and bottom of the tooth, that is to say, a clear enlargement of the outermost area of the female rotor tooth. Even more preferably, the narrowing of the intermediate area of the female rotor tooth is in the order of 50%. In addition to the above-mentioned advantages of better coupling on mating between the rotors, together with the associated sealing advantages, these characteristics also enable an excellent ratio to be achieved between the diameters and centre distance of the rotors, with a consequent excellent flow rate, particularly considering the above-mentioned preferable number of rotor teeth.

Advantageously, both flanks of the profile of each tooth of the female rotor enable a tangent to be drawn from the centre of the rotor. Furthermore, in relation to this tangent, they show a marked "dip" in their profile, that is, a pronounced concavity. This aspect also helps to improve coupling on mating, which greatly improves the seal.

Other characteristics and advantages of the invention will become clear from the following description of a preferred embodiment which is given with reference to the appended drawing, the single Figure 1 of which illustrates a cross-section, perpendicular to the axis of rotation, of two mating rotors according to the present invention, in which the asymmetrical profile of each rotor and the same outer diameter for both rotors are clearly visible.

With reference now to Figure 1, a pair of rotors 10, 11 is intended for use in a rotary screw machine, for example a compressor or vacuum pump, of a type generally known and therefore not described in further detail below. The rotors 10, 11 have respective central cores 12, 13 which, at the end of the rotors, extend to form the rotation shafts of the screws, supported by respective bearings in the box or casing of the rotary screw

machine. Alternatively, the rotors 10, 11 can be drilled through to house respective shafts splined to them.

The threads of the screws of the rotors 10, 11 extend helically along the height of the rotors, and in section they appear as shown in the drawing. In particular, the male rotor 10 has a series of generally convex ridges or teeth 14, corresponding to the section of the threads of the male screw along a transverse plane in relation to the axis of rotation O10 of the male rotor 10. Studies conducted by the applicant have shown that male rotors with three or four threads are preferable, although the production of male rotors with a different number of threads is not excluded from the scope of the present invention.

Each ridge 14 has a tip 15, or point of maximum radius r_{10} , from which extend, on opposite sides, a right-hand flank 16 and a left-hand flank 17. The tips 15 of the ridges 14 define a maximum outer circle C10 of diameter d_{10} . The right-hand flank 16 and the left-hand flank 17 have different profiles, which are asymmetrical in relation to the radius r_{10} passing through the tip 15. Between one ridge 14 and the next, the profile of the male rotor 10 has channel areas 18 of very small diameter.

The female rotor 11 has a series of grooves 18 mating with the ridges 14 of the male rotor 10. Interposed between the grooves 18 are ribs or teeth 19 matching the section of the threads of the female screw along a transverse plane in relation to the axis of rotation O11 of the female rotor 11.

Studies conducted by the applicant have shown that female rotors with six or seven threads are preferable, although the production of female rotors with a different number of threads is not excluded from the scope of the present invention.

In particular, the preferred, although non-limiting, couplings of the present invention are a male rotor having three threads with a female rotor having six threads, or a male rotor having four threads with a female rotor having seven threads.

Each rib 19 of the female rotor 11 has a substantially rounded tip 20, or point of maximum radius r_{11} , from which extend, on opposite sides, a right-hand flank 21 and a left-hand flank 22, mating with the right-hand 16 and left-hand 17 flanks, respectively, of the male rotor 10. The tips 20 of the ribs 19 define a maximum outer circle C11 of a diameter equal to the diameter d_{10} of the male rotor 10, and preferably have no sharp edges or significant cylindrical portions.

From the centre O11 of the female rotor 11 it is possible to draw two straight lines t' , t'' tangent to the two flanks of the same tooth or rib 19. The tangent straight lines t' , t''

touch the profiles of the flanks of the teeth 19 at a middle area of their height, intermediate between the end or tip 20 and the base of the tooth. In this area, there is a significant narrowing of the thickness of the tooth, also shown in the drawing, that may be in the order of 50%.

Of course, being mated with the respective flanks of the ridges 14 of the male rotor 10, the right-hand flank 21 and the left-hand flank 22 of the female rotor also have different profiles, which are asymmetrical in relation to the radius r_{11} passing through the tip 20 of each rib 19.

Advantageously, it has been found that the profiles of the rotors achieve good efficiency if part of the right-hand flank 16 and of the left-hand flank 17 of the male rotor 10 each have a portion of the arc of a circle, and the two portions of arcs of a circle are of an appreciably different size as regards radius, even though they are tangent: the two portions of the arc of a circle describe a part of the right-hand flank 16 and a part of the left-hand flank 17 respectively.

Even more advantageously, it has been found that the profiles are particularly efficient if the common tangent of the two portions of arcs of a circle that describe part of the profile of the right-hand flank 16 and part of the profile of the left-hand flank 17, respectively, of the male rotor 10 is perpendicular to a straight line (r_{10} in the drawing) passing through the centre of the rotor O_{10} and the point common to the two portions of circumference, that is, the tip 15 of the ridge 14.

Mating rotors were deemed to be particularly advantageous where the profile of one ridge 14 of the male rotor 10 is defined by a spline function passing through a plurality of nodal points having pre-established co-ordinates, with a tolerance of $\pm 1/15$, more preferably $\pm 1/20$, and even more preferably $\pm 1/30$ of the profile, that is, the difference between the maximum radius and the minimum radius of the theoretical profiles. The nodal points are defined by a pair of values $\{X', Y'\}$ expressed in a system of Cartesian co-ordinates having their origin in the centre O_{10} of the male rotor 10. Similar considerations apply to the mating female rotor.

The tolerance is measured in a direction perpendicular to the theoretical profile. It is particularly easy to assess the tolerance by describing for each nodal point a circle with a radius equal to the tolerance: the succession of circles permits an immediate understanding of whether a profile falls within the claimed band. Although evident from the following description, it should be explained that the origins of the system of X, Y coordinates are the lines of the axis of rotation of the rotors 10 and 11 on a plane

perpendicular to the said axes, which coincide with the centres O10 and O11 of the circles C10 and C11 of maximum diameter of the male 10 and female 11 rotors.

For practical purposes, it is advantageous if the spline function used describes the arcs of circumference of the male rotor as defined above with a reproduction error such as to have no influence on the production tolerance.

In the present description, the term "spline function" refers generally to any spline function which does not introduce errors, or to a smoothing spline with a smoothing parameter that is sufficiently small not to introduce significant errors in relation to the nodal points.

In a preferred, but non-limiting, embodiment of the present invention, the spline function adopted is a natural cubic spline function, that is, a third-degree interpolating natural spline function.

Although the natural spline offers some theoretical advantages, the choice of the type of spline is not, however, binding because, depending on circumstances and for example on the data format required by the machine tools, a person skilled in the art may find it more convenient to use different spline functions, or even smoothing splines also because some of these spline functions are commonly present and used in CAD and CAD-CAM systems.

In a preferred embodiment, the co-ordinates of the nodal points of the male rotor are homothetic to the pairs of values {X,Y} in the list contained in Table 1 below.

X	Y	X	Y	X	Y	X	Y
50.01	50.01	42.83	1.26	37.06	-4.03	45.21	-14.03
53.80	45.31	41.10	0.29	37.01	-4.30	46.22	-15.46
56.47	39.90	39.43	-0.44	36.89	-5.03	47.25	-17.07
58.05	34.08	39.22	-0.58	36.81	-5.53	48.26	-18.87
58.26	28.03	39.04	-0.71	36.72	-6.12	49.14	-20.91
57.16	22.09	38.86	-0.86	36.73	-6.65	50.00	-23.12
56.59	20.19	38.66	-1.04	36.89	-7.25	50.68	-25.55
55.96	18.30	38.45	-1.24	37.14	-7.73	51.36	-28.14
55.17	16.47	38.24	-1.48	37.80	-8.27	51.82	-30.94
54.37	14.65	38.03	-1.75	38.65	-8.56	52.18	-33.90
53.41	12.91	37.82	-2.07	38.92	-8.67	52.29	-37.03
52.38	11.21	37.61	-2.44	39.33	-8.87	52.13	-40.31
51.31	9.53	37.52	-2.64	39.90	-9.18	51.85	-43.73
50.09	7.96	37.42	-2.85	40.59	-9.61	51.34	-47.28
48.87	6.39	37.34	-3.07	41.39	-10.16	51.13	-48.29
47.51	4.94	37.26	-3.30	42.26	-10.88	50.64	-49.22
46.05	3.59	37.18	-3.54	43.17	-11.78	50.01	-50.01
44.52	2.32	37.11	-3.79	44.15	-12.83		

Table 1

The profile of the female rotor 11 is determined by the condition of mating, once the number of threads has been defined. Of course, for the practical purposes of producing the female rotor, small modifications dictated by experience are made to ensure the correct operating clearance and permit differential thermal expansion, although these small modifications do not influence the fundamental principle of the present invention.

If the male rotor assumes the above-defined configuration, the nodal points through which, as also described above for the male rotor 10 and with the same tolerances, the profile of a rib 19 of the female rotor 11 is defined, are defined by a pair of values {X',Y'} expressed in a system of Cartesian co-ordinates having their origin in the centre O11 of

the female rotor 11, and are homothetic to the pairs of values {X,Y} in the list contained in Table 2 below.

X	Y	X	Y	X	Y	X	Y
64.14	-29.42	60.73	-23.94	37.10	3.37	50.10	22.92
64.19	-28.09	59.90	-23.78	37.13	4.62	51.59	23.56
63.96	-26.78	58.95	-23.53	37.32	6.43	53.13	24.14
63.50	-25.81	57.94	-23.29	37.71	8.77	54.69	24.74
63.29	-25.60	56.87	-22.98	38.18	10.11	56.33	25.20
63.09	-25.43	55.78	-22.55	38.72	11.42	58.02	25.57
62.88	-25.26	53.40	-21.46	39.30	12.72	59.74	25.94
62.68	-25.11	50.75	-19.96	40.03	13.96	63.13	26.27
62.46	-24.96	47.76	-17.93	40.88	15.13	64.29	27.00
62.25	-24.82	44.60	-14.98	41.74	16.31	64.69	28.32
62.04	-24.69	41.51	-10.86	42.68	17.45	64.31	29.59
61.82	-24.55	39.18	-6.41	43.76	18.49	64.04	30.16
61.60	-24.42	37.89	-2.43	44.87	19.51	63.76	30.70
61.39	-24.29	37.39	0.53	46.04	20.50	62.97	31.79
61.17	-24.16	37.20	2.20	47.34	21.35		
60.95	-24.03	37.15	2.68	48.71	22.14		

Table 2

Naturally, the principle of the invention remaining the same, the forms of embodiment and details of construction may be varied widely with respect to those described and illustrated without thereby departing from the scope of the present invention.

CLAIMS

1. Rotors for a rotary screw machine, having asymmetrical profiles, a female rotor of said rotors having teeth whose profiles enable, on opposing flanks of each tooth, a tangent to be drawn from the centre of the rotor.
2. Rotors according to claim 1, having the same outer diameter.
3. Rotors according to claim 1 or 2, with the number of threads of the male rotor being different from the female rotor.
4. Rotors according to claim 1, 2 or 3 with the number of threads of the male rotor being three or four and the number of threads of the female rotor being six or seven respectively.
5. Rotors according to any one of the preceding claims, with the end of the tooth of the male rotor having, from the point of maximum radius, on both flanks, two portions of arcs of a circle of an appreciably different size as regards radius, but tangent, the two portions of the arc of a circle describing a part of the left-hand flank and a part of the right-hand flank respectively, the female rotor having the respective matings in the corresponding area of the bottom of the tooth.
6. Rotors according to claim 5, wherein the common tangent of the two arcs of a circle is perpendicular to a straight line passing through the centre of the rotor and the common point.
7. Rotors according to any one of the preceding claims, wherein the female rotor has teeth with an end that is substantially without sharp edges, the male rotor being consequently without excessively small concave radii of curvature.
8. Rotors according to any one of the preceding claims, wherein the female rotor has teeth whose ends are completely or almost completely rounded and without or almost without cylindrical portions.

9. Rotors according to any one of the preceding claims, wherein the female rotor has teeth with an intermediate narrowed area between the bottom and the end of each tooth.
10. Rotors according to claim 9, wherein the narrowed area has a reduction in thickness in the order of approximately 50%.
11. Rotors according to any one of the preceding claims, wherein the flanks of the teeth of the female rotor are significantly concave relative to the respective tangent drawn from the centre of the female rotor.
12. Rotors according to any one of the preceding claims, wherein the profile of each ridge of the male rotor and the profile of each rib of the female rotor fall within a tolerance band of $\pm 1/15$, more preferably $\pm 1/20$, and even more preferably $\pm 1/30$, respectively, of the height of the profile of the male rotor and of the ridge of the rib of the female rotor, relative to a theoretical profile homothetic to a profile defined by a spline function passing through a plurality of nodal points having pre-established co-ordinates {X,Y} selected from the group comprising the co-ordinates listed in Tables 1 and 2, regarding a ridge of the male rotor and a rib of the female rotor respectively, also set out below:

X	Y	X	Y	X	Y	X	Y
50.01	50.01	42.83	1.26	37.06	-4.03	45.21	-14.03
53.80	45.31	41.10	0.29	37.01	-4.30	46.22	-15.46
56.47	39.90	39.43	-0.44	36.89	-5.03	47.25	-17.07
58.05	34.08	39.22	-0.58	36.81	-5.53	48.26	-18.87
58.26	28.03	39.04	-0.71	36.72	-6.12	49.14	-20.91
57.16	22.09	38.86	-0.86	36.73	-6.65	50.00	-23.12
56.59	20.19	38.66	-1.04	36.89	-7.25	50.68	-25.55
55.96	18.30	38.45	-1.24	37.14	-7.73	51.36	-28.14

55.17	16.47	38.24	-1.48	37.80	-8.27	51.82	-30.94
54.37	14.65	38.03	-1.75	38.65	-8.56	52.18	-33.90
53.41	12.91	37.82	-2.07	38.92	-8.67	52.29	-37.03
52.38	11.21	37.61	-2.44	39.33	-8.87	52.13	-40.31
51.31	9.53	37.52	-2.64	39.90	-9.18	51.85	-43.73
50.09	7.96	37.42	-2.85	40.59	-9.61	51.34	-47.28
48.87	6.39	37.34	-3.07	41.39	-10.16	51.13	-48.29
47.51	4.94	37.26	-3.30	42.26	-10.88	50.64	-49.22
46.05	3.59	37.18	-3.54	43.17	-11.78	50.01	-50.01
44.52	2.32	37.11	-3.79	44.15	-12.83	-	-

Table 1

and also

X	Y	X	Y	X	Y	X	Y
64.14	-29.42	60.73	-23.94	37.10	3.37	50.10	22.92
64.19	-28.09	59.90	-23.78	37.13	4.62	51.59	23.56
63.96	-26.78	58.95	-23.53	37.32	6.43	53.13	24.14
63.50	-25.81	57.94	-23.29	37.71	8.77	54.69	24.74
63.29	-25.60	56.87	-22.98	38.18	10.11	56.33	25.20
63.09	-25.43	55.78	-22.55	38.72	11.42	58.02	25.57
62.88	-25.26	53.40	-21.46	39.30	12.72	59.74	25.94
62.68	-25.11	50.75	-19.96	40.03	13.96	63.13	26.27
62.46	-24.96	47.76	-17.93	40.88	15.13	64.29	27.00
62.25	-24.82	44.60	-14.98	41.74	16.31	64.69	28.32
62.04	-24.69	41.51	-10.86	42.68	17.45	64.31	29.59
61.82	-24.55	39.18	-6.41	43.76	18.49	64.04	30.16
61.60	-24.42	37.89	-2.43	44.87	19.51	63.76	30.70
61.39	-24.29	37.39	0.53	46.04	20.50	62.97	31.79
61.17	-24.16	37.20	2.20	47.34	21.35		
60.95	-24.03	37.15	2.68	48.71	22.14		

Table 2

13. A rotary screw machine comprising a pair of rotors according to any one of the preceding claims.
14. A rotary screw machine according to claim 13, wherein the rotary machine is a screw compressor or a vacuum pump or a motor.

1/1

