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Computer Based Screw Compressor Rotor Design System

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COMPUTER BASED SCREW COMPRESSOR ROTOR DESIGN SYSTEM

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ABSTRACT

Present rotor lobe design systems are limited to the description of surfaces by discrete geometric curves. Profiles in this new design system are developed by iterating a series of over 75 points on each lobe surface. Each of these points is iterated to maintain a minimum clearance with the closest mating point, as shown in Figure 1. A patent is pending for this unique design system.

With the profile captured in a computer file, several other computer programs have been developed to provide the lobe designer with a complete design system allowing him/her to:

* Evaluate leakage and predict performance
* Evaluate mesh contact
* Calculate inlet and exit port geometry
* Calculate loads acting on the rotors
* Evaluate manufacturing feasibility

Full scale manufacture and testing has verified this design system. A medium sized compressor (250.HP) designed by this method demonstrated over 2% higher efficiency and lower operating noise than a rotor designed and manufactured by one of the leading manufacturers. <u>This design system provides higher precision and opens the door to durable female drive systems without the use of hard facing.</u>

INTRODUCTION

The primary focus of this paper is to describe the lobe profile synthesis and performance analysis. Complementary programs have been developed to allow the designer to evaluate manufacturing feasibility, to calculate inlet and exit port geometry, and to calculate loads acting on the rotors. While these programs will not be described, they provide a complete design system.

Profile Synthesis

The profile synthesis is done in three stages. For the first stage the designer must specify the number of male and female lobes, male and female OD, center-distance spacing and offset. The offset is a measure of rotor asymmetry which indicates the location of a female lobe tip relative to two adjacent male lobe tips. For example, an offset of 0.5 indicates that a female tip is positioned equidistant between the two adjacent male tips. All of these parameters are basic except for the offset. This first stage synthesis starts with the basic parameters and gives the designer a suggested value for the offset parameter. A relatively few number of points (40 on each male and female rotor) are used in this stage. The female rotor is roughed out first by having the male tip carve out material on the female surface. Then the designer manually adjusts points near the female tip to give a good practical female rotor. The program then carves out the male surface using each of the female points to sweep past the male rotor. Simple linear assumptions are used in this stage.

The second stage synthesis now refines the lobes using an algorithm that calculates the distance of a point on one rotor to a circle drawn through three successive points on the mating rotor. The distance of each point on one rotor from successive points on the other rotor is calculated for each of 41 increments of rotation of the rotor system. The points and rotation increment where clearance is a minimum are sorted out and displayed to the designer who can then either manually adjust errant points or automatically iterate on a required clearance.

The third stage adds points between the previously defined points and repeats the iteration with this finer mesh of points which incorporates 78 male and 77 female points with 81 increments of rotation. The resulting rotor is shown in Figure 1. Further optimization is accomplished by using a cubic spline interpolation algorithm which fits a curve through the defined points and evaluates the smoothness of this curve by displaying the second derivative at each of the points. Any sudden changes in the second derivatives are reduced by adjusting the dimensions of the errant point. Generally this requires relatively small (.001 to .0001 inches) changes. The final shape is developed using this cubic spline and interpolation method and defines over 750 X and Y coordinates. This file of points is supplied to the machining vendor.

Evaluation of Mesh Contact

The mesh contact parameters of clearance, conjugate deviation, and contact pressure angle are evaluated using an algorithm that calculates these values for two circles in close proximity. Each point on the male rotor and its neighbor points are used to define one circle. Then each point on the female rotor together with its neighbor points is used to define a second circle. The clearance between these two circles is calculated at each rotation increment and the set of points with the smallest clearance is chosen. Conjugate deviation is the distance between (a) the point where the line through these circles intersects the line drawn between the two rotor centers and (b) the point where the line connecting the centers intersects the pitch diameter. The pressure angle is the angle between the line joining the circles and the line joining the centers of the rotors. Table 2 illustrates this information.

Performance Analysis

An analysis program has been developed to calculate leakage through the rotor mesh and to determine flow volumes, wrap angles, volume ratios, and either simple gas (air, hydrogen, butane, etc.) or refrigerant {R22, 410A(AZ20), R134a, R407C(AC9000), R507(AZ50)} performance. Table 3 is a printout of the refrigerant performance analysis. The leakage analysis calculates leakage flow as a function of the Mach number and the pressure differentials for each flow passage. Both the theoretical and total input power are calculated. The total input power includes efficiency losses that are a function of the volumetric efficiency, the mismatch between the exit pressure and the flow passage pressure as well as a simple loss for the drive motor. The resulting efficiencies agree quite well with test data.

CONCLUSIONS

A rotor set designed by this system has been machined by Holroyd and tested by a manufacturer of air conditioning systems. The rotor made using my coordinates operated more quietly and with an average 1.9 percent improvement in overall (kW/Ton) efficiency compared to a similar sized rotor designed and made by a foreign company. Table 1 presents a comparison of the two designs at a single operating point. The quieter operation is probably a result of the smoother surfaces obtained by minimizing the variation in the second derivative of the surface coordinates.

REFERENCES

W.H.Press, S.A.Teukolsky, W.T.Vetterling, B.P.Flannery 1992,
Numerical Recipes in C The Art of Scientific Computing Second Edition, pg. 113 Cubic Spline Interpolation

Table 1 - Performance comparison at a single operating point
(40 F evaporating, 10 F superheat, 100 F condensing temperature)

Rotor design	Test kW/Ton	Analysis kW/Ton
co.'s'	.785	.775
Sundt	.756	.731

Figure 1   Synthesized rotor profile

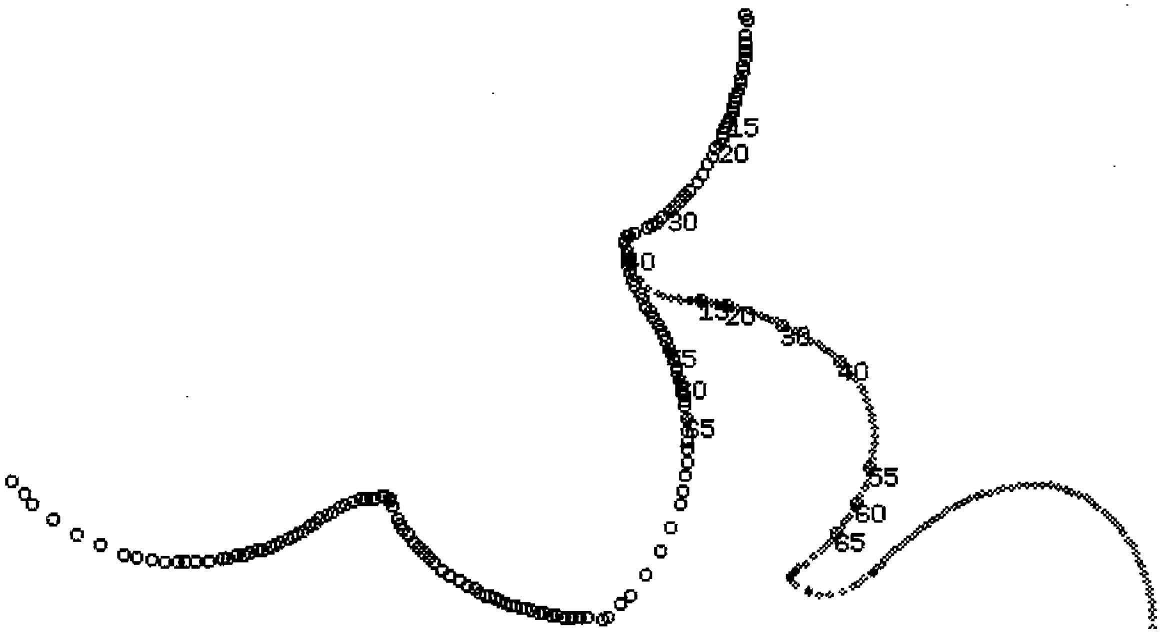

Table 2   Evaluation of mesh contact

Conjugacy analysis with separation of 0.000 and female offset up 0.000
File: DEMO5.COD Optimized

Male Points	Female Points	Clearance		Rotation	Conjugacy deviation	Pressure angle
38_39_40	0_1_2	0.00226	Cave ml	0	0.3336	83.9
39_40_41	1_2_3	0.00067	Cave ml	2	0.0848	79.4
40_41_42	3_4_5	0.00032	Cave ml	3	0.0407	76.3
41_42_43	1_2_3	0.00005	Cave ml	5	0.0040	69.9
42_43_44	2_3_4	0.00005	Cave ml	7	-0.0015	63.0
43_44_45	3_4_5	0.00004	Cave ml	9	-0.0024	56.8
44_45_46	5_6_7	0.00002	Cave ml	11	-0.0053	52.0
45_46_47	6_7_8	-0.00073	Cave ml	13	-0.0493	49.5
46_47_48	4_5_6	0.00015	Cave ml	15	0.0037	43.1
47_48_49	5_6_7	0.00020	Cave ml	18	-0.0012	38.9
48_49_50	5_6_7	0.00019	Convex	20	-0.0029	36.8
49_50_51	6_7_8	0.00017	Convex	22	0.0026	35.5
50_51_52	8_9_10	-0.00005	Convex	24	-0.0034	34.2
51_52_53	7_8_9	-0.00003	Convex	26	0.0016	33.8
52_53_54	7_8_9	-0.00008	Convex	28	-0.0002	33.2
53_54_55	7_8_9	-0.00006	Convex	29	-0.0011	33.0
54_55_56	8_9_10	-0.00003	Convex	31	0.0013	32.9
55_56_57	8_9_10	-0.00007	Convex	32	0.0008	32.9
56_57_58	8_9_10	-0.00004	Convex	34	-0.0002	32.8

Conjugacy analysis with separation of 0.000 and female offset up 0.000
File: DEMO5.COD Optimized

Male	Female	Clearance		Rotation	Conjugacy	Pressure
57_58_59	9_10_11	-0.00003	Convex	35	0.0011	32.8
58_59_60	9_10_11	-0.00006	Convex	37	-0.0031	33.1
59_60_61	9_10_11	0.00007	Convex	38	-0.0035	33.1
60_61_62	10_11_12	0.00011	Convex	39	0.0004	33.2
61_62_63	10_11_12	0.00003	Convex	40	0.0020	33.3
62_63_64	10_11_12	0.00010	Convex	42	-0.0023	33.8
63_64_65	11_12_13	0.00014	Convex	43	-0.0009	34.0
64_65_66	12_13_14	0.00012	Convex	45	-0.0001	34.6
65_66_67	12_13_14	0.00022	Convex	47	-0.0105	35.4
66_67_68	15_16_17	0.00029	Cave fe	47	-0.0055	36.4
67_68_69	16_17_18	0.00032	Cave fe	48	0.0049	39.9
68_69_70	16_17_18	0.00009	Cave fe	49	0.0164	43.3
69_70_71	18_19_20	-0.00028	Cave fe	50	0.0164	45.9
70_71_72	19_20_21	-0.00064	Cave fe	51	0.0167	48.6
71_72_73	22_23_24	-0.00085	Cave fe	52	0.0045	50.5
72_73_74	26_27_28	-0.00082	Cave fe	53	-0.0103	52.4
73_74_75	28_29_30	0.00055	Cave fe	55	-0.0613	54.8
74_75_76	31_32_33	0.00117	Cave fe	56	-0.0133	62.7
75_76_77	34_35_36	0.00075	Cave fe	57	-0.0090	67.5
76_77_78	35_36_37	-0.02226	Cave fe	58	-0.4332	-21.7

Precision is 1.00   Hit any key to return

Table 3 Performance analysis

```
Flow Analysis for AZ20 (50% R32 - R125)
   DEMO5.DTA Optimized
Number of male lobes is 4: female is 7: Number of spools is 2
Male area is 1.197 sq.in: Female area is 0.995 sq.in: Taper is 1.00
Helix angle is 44.9300 deg. or 44 deg. 55 min. 48 sec.
Male wrap angle is 300.069 -- Exhaust modification is -38
Male OD 106.680 mm.(4.2000 in.): Female OD 106.680 mm.(4.2000 in.)
Centerline distance 83.820 mm. (3.3000 in.): Offset 0.350
Male pitch dia. 60.960 mm(2.4000 in.): Female 106.680 mm(4.2000 in.)
Male root dia. 60.826 mm.(2.3947 in.): Female 60.861 mm.(2.3961 in.)
Equivalent axial length -t- is 0.0461 in. -- L/D for male is 1.5000
Max. length/length 1.08 in.(.9 to 1.2): Length 160.020 mm(6.3000 in)
Origin for angles is where male tip is on horizontal line at the exit
Start exhaust at -27 t (116.35 deg.) - Closure at 27 t (-2.20 deg.)
Male tip to female housing at 38.0 t (-26.34 deg.) - Tmax is 10.3
Exit tip to tip at 10 t (35.13 deg.) -- Overlap constant is 0.977
Leakage area is 0.437  -- Volume efficiency is 0.955
Single passage inlet volume 13.5 cu.in.: exit volume 6.6 cu.in.
Volume ratio (no leakage) is 0.493--Pressure ratio is 4.391
1/Volume ratio (no leakage) is 2.030
Unit flow per revolution of male 0.885 L./rev. (54.0 cu.in./rev.)
Unit flow per revolution of female 1.548 L./rev.(94.5 cu.in./rev.)
Design male speed is 3550.0 RPM (Female speed is 2028.6 RPM)
Theoretical (no leak) volume flow is 3.1 cu.m/min (110.9 scfm)
   Hit a key to continue

            Analysis for AZ20 (50% R32 - R125)
Theoretical (with leak) mass flow is 1.45 kg./s (3.20 lb/s)
Evaporating temp. is -1.1 C (30.0 F) superheating is 0.0 C (0.0 F)
Condensing temp. is 54.4 C (130.0 F) subcooling is 0.0 C (0.0 F)
Quality is 1.000 -- C.O.P is 2.16 -- Male tip speed is 19.83 m/s
Capacity is 181.8 KW (51.7 Tons) -- Oil flow is 6.0 gal./min.
Used oil mass flow to refrigerant mass flow is 2.205:100
Pressures - inlet 770.1 kPa(111.7 psi) - exit 3381.7 kPa(490.5 psi)
Compressor exit temperature is 75.5 C (168.0 F)
Compressor exit temperature with leak is 92.1 C (197.8 F)
Theoretical power input is 62.5 KW -- Dynamic power loss is 10.1 KW
Total power is 72.6 KW (97.3 Hp)  : KW/Ton is 1.4033
Total drive torque is 195.2 Nm (144.0 ft.lbs.)
Adiabatic efficiency is 0.861 (with leak 0.855)
Male torque is 211.1 ft.lbs.--female torque is -23.8 ft.lbs.

Input values
k is 1.04, Mn is 0.11, T1 is 1.0, P1 is 7.601, P2 is 33.37
Rg is 65.98, Clt is -38, Added Leak is 0.0000
power loss factor is 0.00

Enter 1 for revised helix angle,  2 to save flow area,  0 to return
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