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OPTIMUM LOBE TIP DESIGNS IN OIL INJECTED HELICAL TWIN SCREW COMPRESSORS

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ABSTRACT

The effects of lobe tip design parameters on compressor performance were evaluated by utilizing a computer simulation package and taking SRM-D asymmetric type rotor profile as an example. The result suggests that the requirements for high efficiency, large capacity, low inter-rotor contact force and low viscous friction loss do not always lead to the use of the same lobe tip designs. Of all the tip parameters, special attention should be given to the male rotor crest range angles and the female rotor addendum, since they have a greater influence than all other rotor tip parameters.

NOMENCLATURE

A	Addendum of the female rotor, mm
C	Centre distance between the male and female rotors, mm
r_3	Radius of the male rotor tip segment, mm
r_6	Radius of the male rotor minor circular arc, mm
\bar{z}_1, \bar{z}_2	Lobe numbers of the male and female rotors, respectively
β_3	Leading angle of the male rotor tip segment, deg
β_4	Trailing angle of the male rotor tip segment, deg

1 INTRODUCTION

Modern rotor profiles have made possible the design and manufacture of high efficiency twin screw compressors. However, making the right choice of rotor profile is not on its own enough to ensure a high performance screw compressor. One of the major characteristics of the design process of a modern rotor profile, like the SRM D-profile, is its flexibility; ie within its definition a range of profiles can be produced. These profiles can be applied to various applications with the potential of obtaining high performance. However, the profile parameters must be chosen carefully.

The definition of a rotor profile usually requires many parameters. Each parameter may influence the compressor performance in one or more aspects. The pressure angles at the pitch circle of the male rotor, for instance, govern whether the rotors are easy to machine, while the width of the female rotor lobes affects the rigidity of the rotor. In this study not all of these profile parameters but only those which influence the design of lobe tips are discussed. Compared with certain other performance influencing parameters, the effect of lobe tip design parameters are relatively small and therefore have received comparatively little attention.

The demands for compressor high efficiency, long rotor life and high capacity/power ratio are always present. High efficiency requires low leakage. One of the main leakage paths in the twin screw compressor is its so called blow hole, the size of which is to a great extent determined by the lobe tip designs.

Long rotor life requires low inter-rotor contact force. The contact force between the rotors is related to the torque transmitted directly from one to the other. Most helical twin screw compressors utilize male rotor drive. The advantage of this arrangement is that only a small part of the input torque is transmitted to the female rotor. As can be seen later in this paper, the ratio of transmitted torque to the input torque, is influenced considerably by the lobe tip designs.

Lobe tip designs also affect the viscous friction power loss in an oil injected compressor. An analysis of this kind

of power loss has been reported by the authors previously [1], in which the effects of different tip design parameters were evaluated.

In general, the requirements for high efficiency, low contact force and high capacity/power ratio do not always lead to the use of same lobe tip design parameters. Indeed, a compromise is often needed and the tip design parameters must be optimised accordingly.

Taking the SRM D-profile as an example and utilizing the performance simulation program and the force analysis program developed by the authors [2-4], a parameter study has been carried out. In this paper, the influence of lobe tip design parameters is discussed and optimum design suggestions are presented.

2 COMPRESSOR SPECIFICATIONS AND RUNNING CONDITIONS

As shown in Fig. 1, the main parameters defining the tips of the SRM D-profile include the radius of the male rotor crest r_3 , its corresponding range angles β_3, β_4 , the radius of the minor circular arc r_6 and the female rotor addendum A . From the geometry of the rotors, the radius of the male rotor crest r_3 can be expressed as

$$r_3 = C \cdot \left(\frac{\bar{z}_2 - \bar{z}_1}{\bar{z}_1 + \bar{z}_2} + \frac{A}{C} \right) \quad (1)$$

It can be seen that the centre distance C , the female rotor addendum A and the lobe combination may all influence the value of r_3 . C and A are discussed in this paper, while lobe combination is dealt with in another paper [5].

To evaluate the effects of these parameters, it would be ideal if each time only one parameter could be changed. However, due to the complexity of the profile geometry, a change in one parameter may result in a significant change of other parameters. One example is the female rotor addendum A , a change of which may cause a change in r_3 as shown in Eq. 1. Unless otherwise specified, the parameters and running conditions used in this study are as follows.

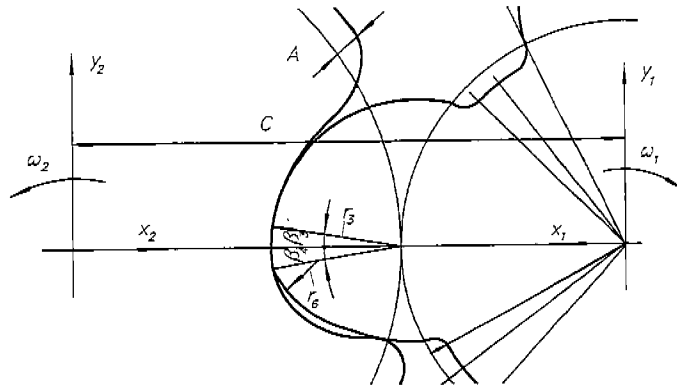


Fig. 1 Rotor tip of SRM D-profile

The specifications of the compressor used for the calculation:

- | | |
|---|---------------|
| • Rotor profile and lobe combination: | SRM-D, 4/6 |
| • Outer diameter and centre distance of the rotors: | 204, 160 mm |
| • Length / diameter ratio and male rotor wrap angle: | 1.65, 300 ° |
| • Volume ratios for radial and axial discharge: | 2.6 and 5.0 |
| • Radius of the male rotor crest r_3 over C : | 23.725 % |
| • Range angles of the male rotor crest β_3, β_4 : | 8.0 °, 15.0 ° |
| • Radius of the minor circular arc r_6 over C : | 7.50 % |
| • Addendum of the female rotor A over C : | 3.725 % |

The running conditions used for the calculation:

- Compression medium: R22
- Male rotor driving speed: 3000 rpm
- evaporating and condensing temperature: -5, 40 °C
- Suction and discharge pressure: 4.21, 15.34 bar
- Oil injection rate and temperature: 150 kg/min, 40 °C

In addition, the following definitions are used:

$$\text{Input torque} = \text{Male rotor torque} + \frac{z_1}{z_2} \cdot (\text{Female rotor torque})$$

$$\text{Transmitted Torque Ratio (TTR)} = \frac{\text{Female rotor torque}}{\text{Input torque}}$$

Maximum Contact Force - The maximum inter-rotor contact force per unit length of the power transmission section of the contact line^[4].

The computer programs used in this paper form a powerful package capable of performance simulation and force analysis for various compressor specifications and running conditions. The programs were verified by comparing the predictions with the measured data for the same type of rotor profile and similar compressor specifications and running conditions as used in this study. Therefore, the authors believe that the simulation results in this study are of the same level of reliability.

3 RESULTS AND DISCUSSION

Effects of the Range Angles β_3, β_4

The effects of the male rotor tip leading angle β_3 are shown in Fig. 2. It is interesting to note that although the real capacity of the compressor increases somewhat with increasing β_3 , the transmitted torque ratio and maximum rotor contact force are significantly reduced. In addition, the increase in β_3 does not cause an increase in blow hole leakage loss, as can be seen from the almost unchanged volumetric efficiencies. In fact, both the volumetric and indicated efficiencies achieve their highest values when β_3 is about 30°. This means that a relatively larger β_3 would be an advantage from the point of view of compressor high efficiency, large capacity and low inter-rotor contact force.

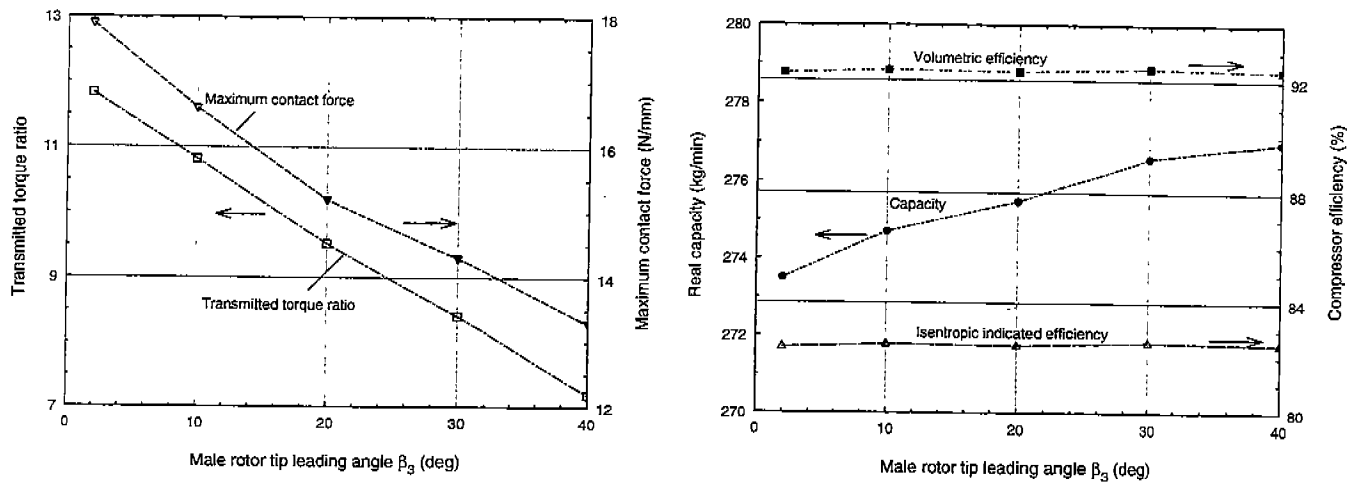


Fig. 2 Effects of male rotor tip leading angle β_3

However, this is in conflict with the requirement for a low viscous friction loss in an oil injected machine. The analysis conducted by the authors has suggested that a relatively small male rotor tip leading angle β_3 could reduce the viscous friction power loss at lobe tips to some extent^[1]. Therefore, optimisation is required if the highest capacity/power ratio and an acceptable inter-rotor contact force are to be achieved for a specified application.

In contrast, an increase in the range angle β_4 causes an increase in the transmitted torque ratio and the maximum contact force, as shown in Fig. 3. Also, the compressor real capacity decreases slightly with increasing β_4 and both the volumetric efficiency and isentropic indicated efficiency obtain their highest value at the smallest β_4 . Thus, from this point of view, a small β_4 is preferable. Considering the viscous friction power loss at the lobe tips, a small trailing tip angle β_4 is also an advantage^[1]. Therefore, choosing β_4 becomes straightforward, the smaller the better.

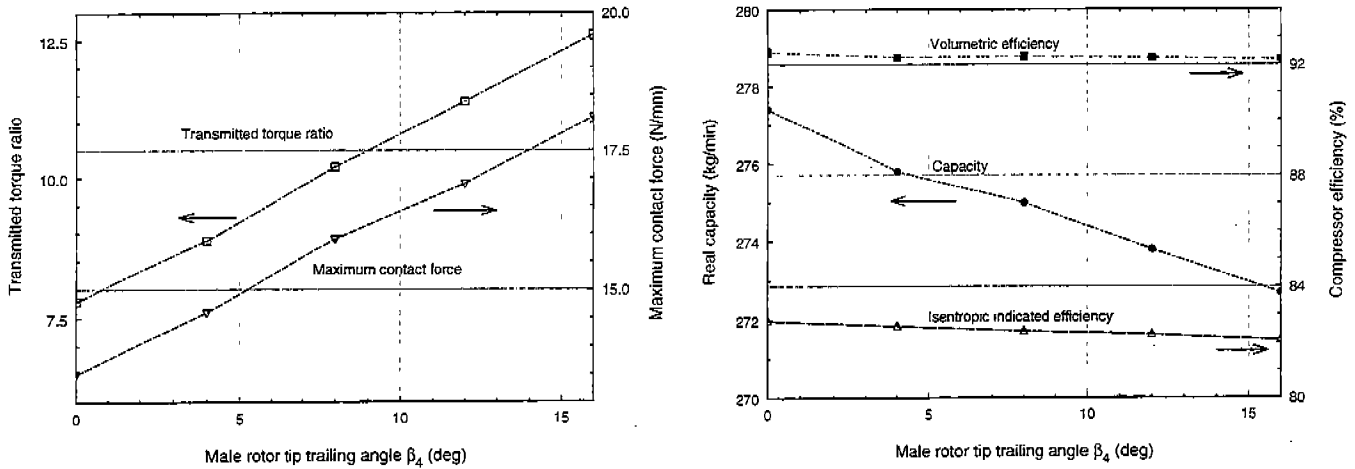


Fig. 3 Effects of male rotor tip trailing angle β_4

To examine the overall effects of β_3 and β_4 together, five different combinations were studied and the results are presented in Table 1.

Table 1 Effects of different combinations of β_3 and β_4

Items	Angle combinations β_3 / β_4				
	2 / 16	8 / 12	15 / 8	20 / 6	40 / 2
Female rotor torque (Nm)	142.1	124.5	103.4	88.1	51.9
Transmitted torque ratio	14.61	12.31	10.20	8.66	5.07
Maximum contact force (N/mm)	20.4	18.0	15.9	14.3	11.1
Real capacity (kg/min)	261.1	272.9	275.0	275.9	278.6
Volumetric efficiency (%)	91.89	92.16	92.29	92.28	92.36
Isentropic indicated efficiency (%)	81.83	82.20	82.41	82.49	82.64

The importance of choosing the right combination of β_3 and β_4 is obvious from the above table. The real capacity for $\beta_3 / \beta_4 = 40 / 2$ is increased by 6.7 percent compared with that for $\beta_3 / \beta_4 = 2 / 16$ and the transmitted torque and the contact force are reduced by about 60 percent and 46 percent, respectively. As can be seen, this is accompanied by a 0.47 % higher volumetric efficiency and a 0.81 % higher isentropic indicated efficiency.

Effects of the Radius of the Circular Arc r_6

Similar to the tip trailing angle β_4 , the effects of the radius of the circular arc r_6 are straightforward (see Fig. 4). With the decrease in r_6 , the transmitted torque and the maximum contact force are all reduced, while the compressor capacity, volumetric and isentropic indicated efficiency are all increased. Obviously, a small r_6 is preferable from this point of view.

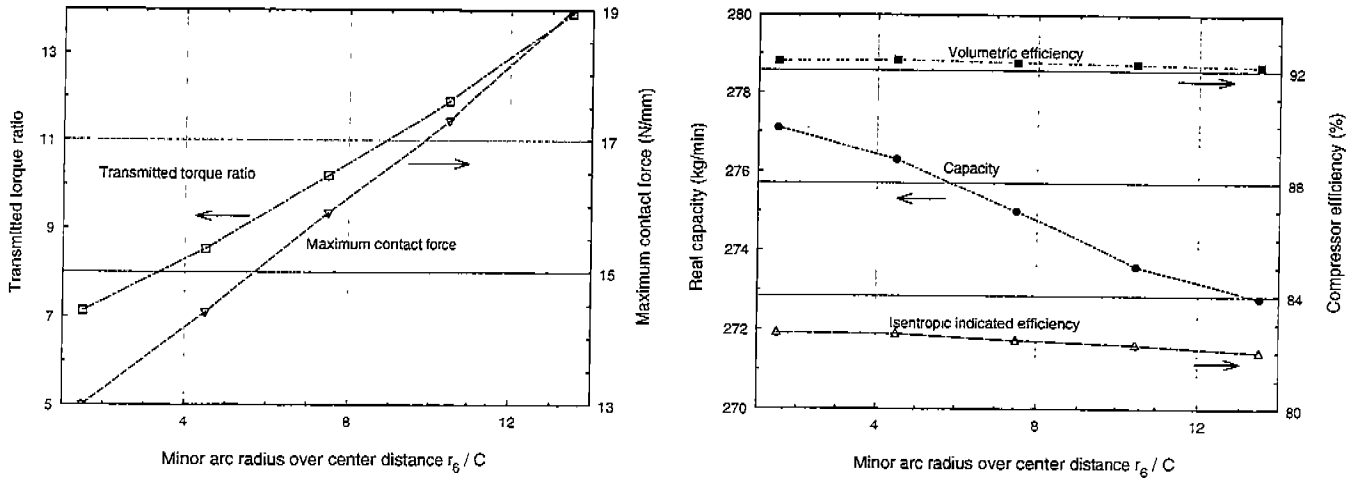


Fig. 4 Effects of minor arc radius r_6

Effects of the Female Rotor Addendum A

The effects of the female rotor addendum are shown in Fig. 5. As can be seen, the smaller the ratio A/C , the lower the transmitted torque ratio and the lower the maximum contact force between the rotors. The isentropic indicated efficiency also increases with decreasing A/C . However, this tendency is offset by the decrease in actual capacity with the decrease in A/C . Therefore, a balanced view must be taken when designing a helical twin screw compressor. In this example, an A/C of about 3.5 percent would be an appropriate choice, which gives a relatively high capacity of 275.0 kg/min with the highest volumetric efficiency of 92.29 percent and an acceptably high indicated efficiency of 82.41 percent.

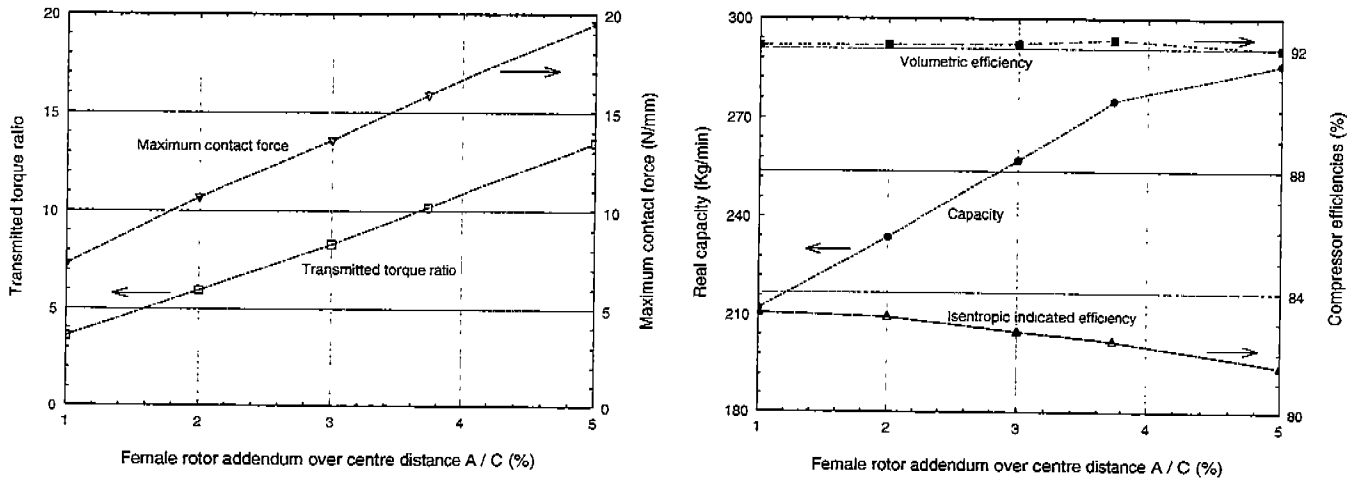


Fig. 5 Effects of the female rotor addendum A

Effects of the Centre Distance C

Fig. 6 shows the results of changing the centre distance C . Since the capacity of the compressor increases with increasing centre distance, the input torque and the female rotor torque are increased, resulting in an increased contact force. However, it can be seen that the transmitted torque ratio remains almost unchanged. In this example, although the values of r_3 and r_6 increase with the increase in centre distance, their ratios over centre distance are kept constant ($r_3/C = 23.75\%$, $r_6/C = 7.5\%$). This implies that the transmitted torque ratio mainly depends upon the shape of the lobe tips, the centre distance of the rotor has little influence on it.

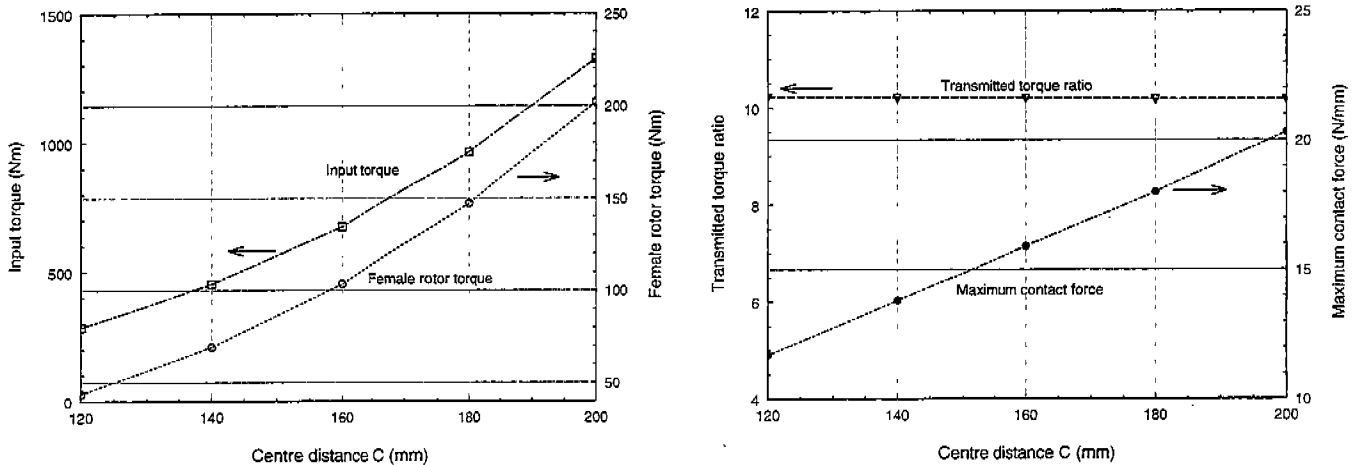


Fig. 6 Effects of the centre distance C

4 CONCLUSIONS

The following conclusions can be drawn from this study:

- (1) From the point of view of obtaining high efficiency, large capacity/power ratio and low inter-rotor contact force, the lobe tip parameters should be chosen as follows:
 - the male rotor crest range angle β_3 should be optimised for the minimum power consumption.
 - Tip segment trailing angle β_4 should be small.
 - Female rotor addendum A should be relatively large, with an A/C ratio of about 3.5 percent.
 - A small value is preferable for the radius of the minor circular arc of the male rotor r_6 .
- (2) The transmitted torque ratio is to a great extent determined by the male lobe tip segment designs, while the influence of the centre distance is relatively small.
- (3) The influence of lobe tip design parameters should not be underestimated.

Finally it is worth stressing that the discussions in this paper are limited to the SRM-D asymmetric type profiles. For other profile types optimization is needed for individual applications.

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