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Hamdy Mahfouz
Universiti Technologi Malaysia

Md Nor Musa
Universiti Technologi Malaysia

Mat Nawi Bin Wan Hassan
Universiti Technologi Malaysia

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Hamdy Mahfouz [1] , Md Nor Musa[2] , Mat Nawi Bin Wan Hassan[3]

[1] Universiti Teknologi Malaysia (UTM), Faculty of Mechanical Engineering,
Johor, Malaysia
Contact Information (Tel 607-5534769, Fax 607-5566159, E-mail- mahfouze@hotmail.com

[2] Universiti Teknologi Malaysia (UTM), Faculty of Mechanical Engineering,
Johor, Malaysia
Contact Information (Tel 607-5534567, Fax 607-5566159, E-mail- mdnor@fkm.utm.my

[3] Universiti Teknologi Malaysia (UTM), Faculty of Mechanical Engineering,
Johor, Malaysia
Contact Information (Tel 607-5534755, Fax 607-5566159, E-mail- matnawi@fkm.utm.my

ABSTRACT

A scroll–wrap profile is an important factor affecting the performance and reliability of scroll fluid machines. A number of geometric curves have been used to form the working surfaces of the scroll machines. The involute of a basic circle is widely used in the design of the scroll compressor. This type of curve is characterized by its variable curvature, hence in manufacturing the machine tools needed a special software to produce the required curvature. In this paper a new profile known as "The Basic Hexagonal involute" has been studied in an attempt to make the manufacturing of the scroll easier, accurate and without the use of the software. This paper discusses the method of designing this profile, and the determination of its volumes. The paper also discusses a comparison between the new hexagonal involute, the basic circle, and square involute. The comparison includes the volume and the arc length for leakage, which affect directly on the performance of the scroll compressor. The thermodynamic comparison analysis for the basic circle and hexagonal are also included

1. INTRODUCTION

The main component of the scroll compressor is an identical pair of scroll spirals, which slide on each other to form the working chambers for the suction, compression and discharge. The leakage, heat transfer, and friction between the working fluid and the profile depend on the geometrical curvature of the scroll spirals. A number of geometrical curves have been adapted as a scroll wrap configurations; examples include the involute of the basic circular type (L.Creux ,1905), the involute of a semi circle (M. Hayano., S. Nagatomo, H.Sakata and M.Hatori,1986), the involute of the basic square (WangZongyan, 1992), and algebraic spiral scroll (H.Hohokable, M.Takebayashi, Y.Kunugi, 1996). In this paper a new profile known as "The Basic Hexagonal Involute" has been analyzed. Using the volume, start angle and the equivalence radius as the fixed parameters, the volume ratio, wrap length, end angle and end point radius were evaluated and compared with those of the basic circle involute

2. HEXAGONAL SCROLL GEOMETRY

Fig 1 shows the basic hexagonal involute. As in the case of generation of profile of basic circle, the profile formation of the new involute can also be created by unwrapping a string from a hexagon and keeping the string taut, the end of the string will trace out the shape of the involute of basic hexagon.

In a hexagonal involute a series of sectors with different centers and radii is employed and the angle between each radius is constant and equal to 60 degree, as shown in Fig.1. The hexagonal involute consists of six different centers at the six apices of the hexagon. The center of the first sector of the involute is the hexagonal vertex "1",

and its sector radius is equal to the hexagonal length "a". The center of the second radius is vertex 2 on the hexagon, and its value equals to the previous radius plus the hexagonal length "a". The third, fourth, fifth, and sixth sectors can be generated by the same way. The seventh sector center starts again from the first hexagonal
Vertex 1, and determination of the other sectors is repeated in the same manner. An example for calculating the involute radii related to the side length of the hexagon and the thickness of the wrap (t) is as follows:

1- When the thickness is less than the length of the hexagon Fig 2

A-Outer involute

R_{1O} = a, R_{2O} = 2a, R_{3O} =3a, R_{4O} = 4a, R_{5O} =5a ,R_{6O} = 6a,
R_{7O} (which starts at R_{1O} center)= 7a, R_{8O} (which starts at R_{2O} center) =8a,
and so on. Then R_{JO} = J. a

B-Inner Involute

R_{1I}= a – thickness, R_{2I}= 2a– thickness, R_{3I} =3a – thickness, R4I = 4a – thickness,R_{5I} = 5a – thickness, and so on,
R_{JI}= J. a – thickness

2- When the thickness is greater than the length of the hexagon Fig 3

A-Outer involute

R_{1O} = a, R_{2O} = 2a, R_{3O} =3a, R_{4O} = 4a, R_{5O} =5a, R_{6O} = 6a,
R_{7O} (which starts at R_{1O} center)= 7a, R_{8O} (which starts at R_{2O} center) =8a,
and so on
R_{JO} = J. a

B-Inner Involute

R_{1I}= 0.0, R_{2I}= 2a– thickness, R_{3I} =3a – thickness, R_{4I} = 4a – thickness,
R_{5I} = 5a –thickness, and so on
R_{JI}= J. a – thickness

The basic geometric variables which determine the scroll profile are the hexagonal length "a", the involute of the starting angle, the involute of the ending angle and the thickness angle.
The orbit radius can be obtained from the following formula

$$\text{Radius of orbit or eccentricity} = \frac{Pitch - 2 \times Thickness}{2}$$

The scroll pitch can be defined as the linear distance between any point on the scroll wrap and the following point after adding 2 π on wrap, which is equal to "6a" in the hexagonal profile.

3-VOLUME OF THE INVOLUTE

The geometric evaluation of the suction, compression and discharge volumes is essential in determining the compressor performance. The geometric relationships and the formulation for the volume are given in (H. Mahfouz, M. N. Hassan, M. N Musa , 2002):

3.1- Suction volume

Suction volume = $2hAs(q)$

$$\text{Where: } As(q) = \frac{1}{2}\sum_{f\ at\ q}^{f=f_e} R_{inner}^2\, df - \frac{1}{2}\sum_{f\ at\ (q-p)}^{f=(f_e-p)} R_{outer}^2\, df + \text{area ABCD}$$

The hatched area ABCD as shown in Fig 4 vary with the scroll rotation.

3.2- Compression Volume

Compression volume = $2hAc(\theta)$

Where: $$Ac(\theta) = \frac{1}{2}\sum_{\phi\ at\ (\theta-2\pi)}^{\phi\ at\ \theta} R^{2}_{inner}\, d\phi - \frac{1}{2}\sum_{\phi\ at\ (\theta-3\pi)}^{\phi\ at\ (\theta-\pi)} R^{2}_{outer}\, d\phi$$

3.3-Discharge Volume

Discharge volume = $2hA_d(\theta)$

Where: $$Ad(\theta) = \frac{1}{2}\sum_{\phi_s}^{\phi_1} R^{2}_{inner}\, d\phi - \frac{1}{2}\sum_{\phi_s-\pi}^{\phi_1-\pi} R^{2}_{outer}\, d\phi + \text{Clearance area}$$

where the clearance area is the segment ABC of the cutter circle, and the involute angle at this point A is the discharge angle, where the compression pocket terminates and the discharge pocket starts.

4-WRAP LENGTH

It is important to study the wrap length in the scroll compressor because it directly affects the amount of leakage from the high pressure to low pressure levels and reduce the volumetric efficiency of the machine.

In basic circle involute the wrap length between two points on the profile can be evaluated by this formula

$$L_C = \int_{\phi_1}^{\phi_2} a\phi \quad d\phi$$

As in the square and hexagonal involute the arc length can be calculated by summing up of its arc length.

In this comparative study, it is assumed that the wrap height and the wrap thickness of the three involute are constant and equal to 33.25mm and 4.58 mm respectively. Three different circle radii were selected to calculate the volume, volume ratio, wrap length, end point radius, and end angle as shown in Table 1. The equivalent radius for the three different involute is based on the basic circle radius, and is shown in Fig5. The starting point was fixed for all cases and it was chosen at 180 deg.

Table 1

Type of profile	v (cm^3)	Volume ratio	% Increase	Wrap length "W" mm	% Increase	Equiva-lence Radius "a" mm	End point radius "R end" mm	% Increase	End angle "deg"	% increase
Circle	43.60	2.509	0 %	440.61	0 %	3.205	53.24	0 %	950	0%
Hex	43.60	2.587	3.1 %	489.00.	10.9 %	3.205	54.35	2.08%	1016	6.94%
Square	43.60	3.400	31.4 %	613.00	39.1 %	3.205	60.12	12.92%	1194	25.68%
Circle	64.80	2.509	0 %	509.20	0 %	3.705	61.55	0 %	950	0%
Hex	64.80	2.550	1.6 %	558.30	9.6 %	3.705	62.38	1.34%	1009	6.21%
Square	64.80	3.336	32.96%	684.00	34.3%	3.705	68.36	11.06%	1174	23.57%
Circle	77.20	2.509	0 %	544.00	0 %	3.959	65.76	0 %	950	0%
Hex	77.20	2.550	1.6 %	595.00	9.3%	3.959	66.59	1.26%	1008	6.1%
Square	77.20	3.326	32.56%	723.00	32.9 %	3.959	72.73	10.59%	1168	22.9%

From the above calculated results it is clear that the hexagonal involute is not too far from that of the basic circle involute except that wrap length differs from 9.3 to 10.9 in these cases. The study also shows that in the case of the basic square involute the variation is between 32.9 to 39.1% and in the semi circle involute the arc length is bigger than that of the basic square (L. Li, P.Shu,Y.Yu , 1996). The hexagonal formulation can be extended to octagonal involute and it is expected that the octagonal involute will produce a better wrap length and close to the basic circle involute and at the same time is easy to manufacture.

The theoretical power is the ideal work necessary to compress the gas from the suction pressure p_1 to the discharge pressure p_d and is given by the following formula:

$$\text{Work /unit mass} = \frac{n}{n-1}\frac{p_1}{r}\left[\left(\frac{p_2}{p_1}\right)^{((n-1)/n)} - 1\right]$$

If we fix the suction volume and the suction pressure and temperature, then the density also will be constant and the above formula can be reduced to

$$\frac{\textit{work required for basic hexagonal involute}}{\textit{work required for basic circle involute}} = \frac{\left[\left(\frac{p_2}{p_1}\right)^{((n-1)/n)} - 1\right]_{\textit{for hexagonal}}}{\left[\left(\frac{p_2}{p_1}\right)^{((n-1)/n)} - 1\right]_{\textit{forbasiccircle}}}$$

The result shows that the work ratio comparison between hexagonal and circle involutes is 1.036 at the volume of 43.6 cm^3, suction pressure equals to 351000 Pa, and it is considered that the discharge pressure equal to the pressure at the end of the compression. This difference resulted from the pressure ratio difference.
To reduce the cost of manufacturing the hexagonal involute provides an alternative solution as there are six reference points used in manufacturing of the scroll involute. Where as, in the basic circle involute infinite number of reference points are required.

5-CONCLUSION

In this paper a new profile known as "The Basic Hexagonal involute" has been presented in an attempt to make the manufacturing of the scroll easier, accurate and without the use of the software. The results show that the end point radius is very close to that of the basic circle involute. The paper explained the method of designing this profile, discussed a comparison between the current involutes, the basic circle, and the square involutes.

NOMENCLATURE

a	Radius of generating circle, hexagonal length or equivalence radius for square	t	Wrap thickness
		R	Radius of the generated involute in hexagonal
		R_{JO}	Radii of the outer involute
R_{JI}	Radii of the inner involute	As	Suction area
h	Scroll height	f	Wrap angle
θ	Crank angle	r	Density
v	volume		

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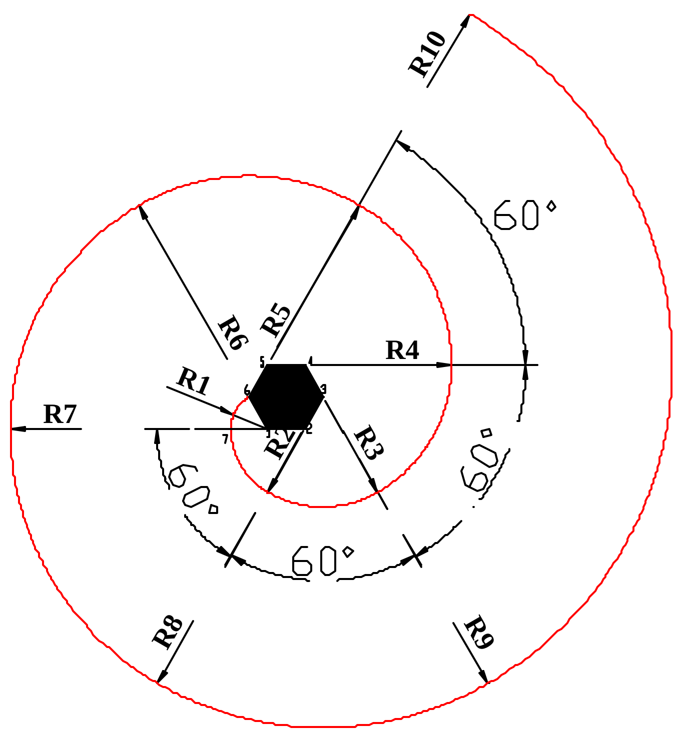


Fig. 1 Generation of a hexagonal profile

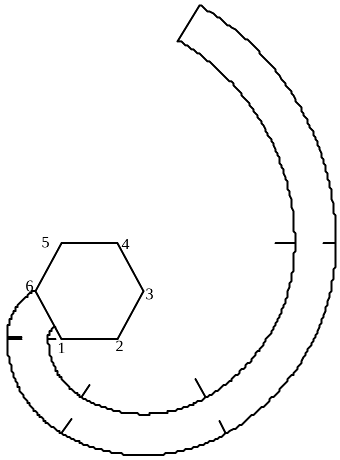


Fig 2 Generated profile with thickness smaller than the hexagonal length

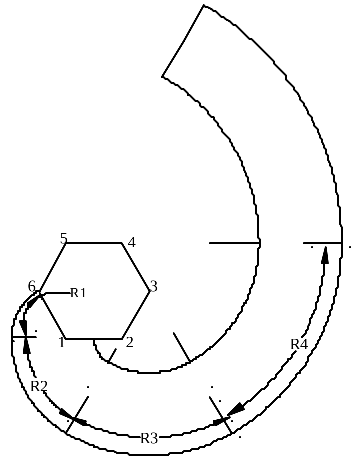


Fig 3 Generated profile with thickness bigger than the hexagonal length

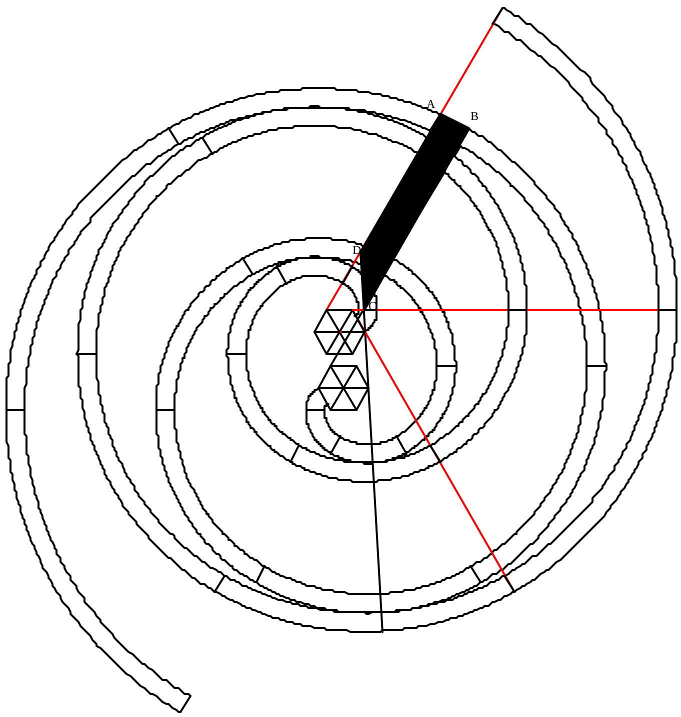


Fig. 4 Hatched area ABCD for calculating suction volume

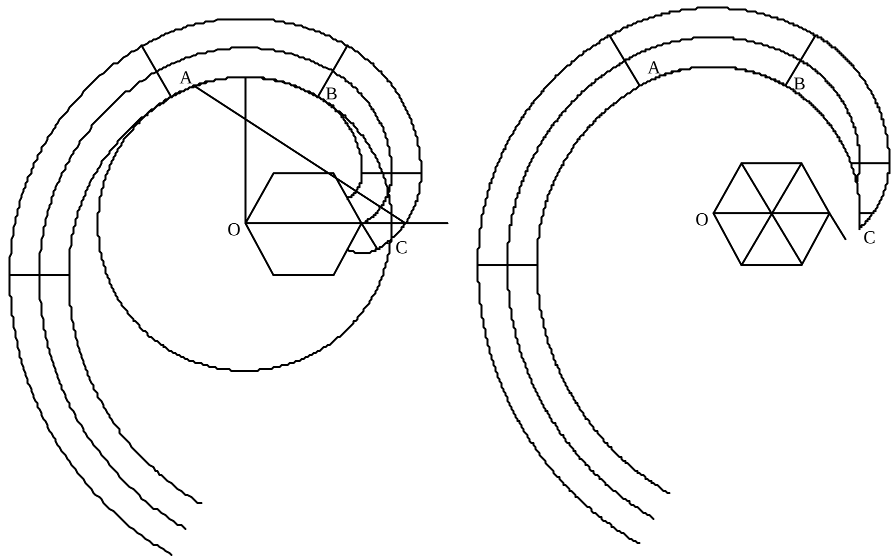


Fig .5 Clearance Volume

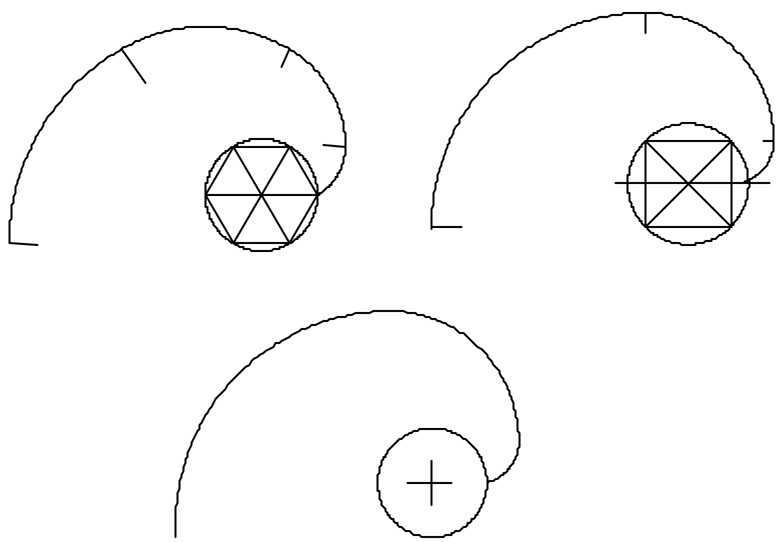


Fig. 6 The equivalence radius

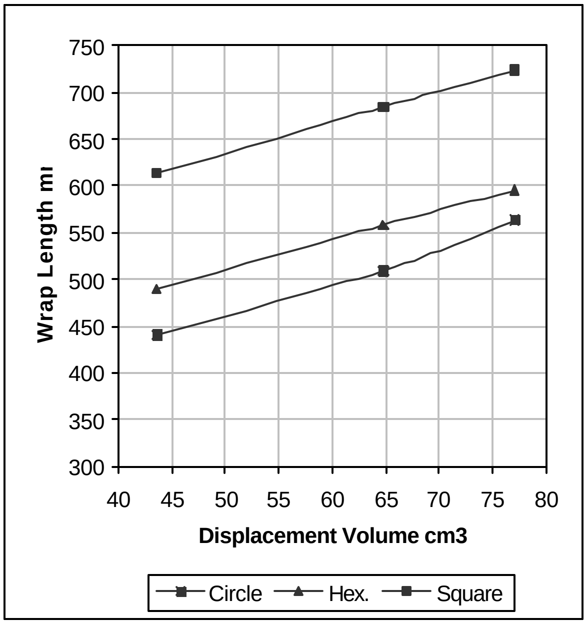


Fig.7 Wrap length

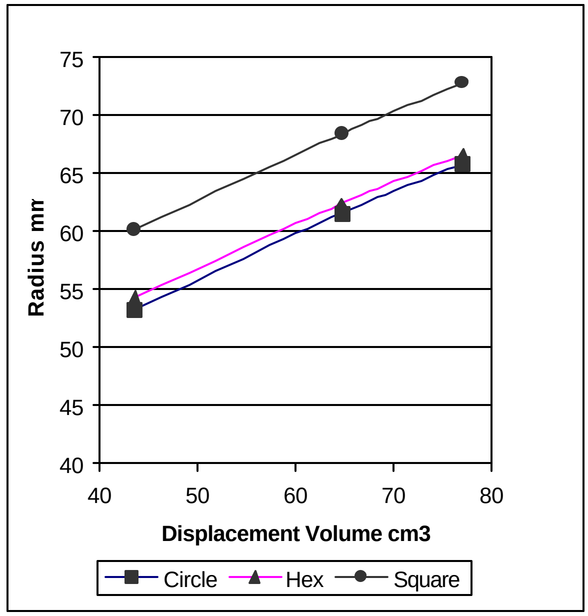
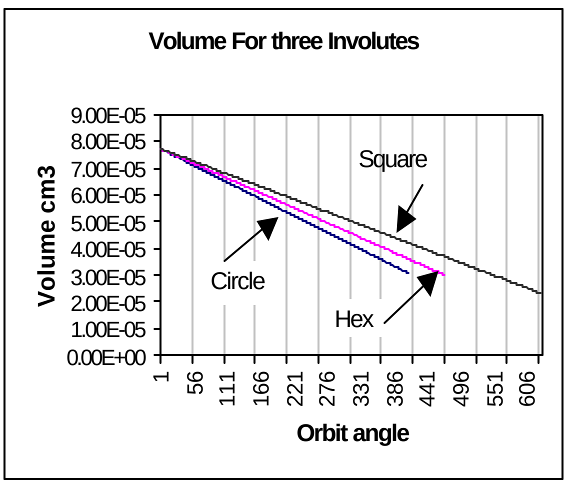


Fig. 8 End Radius



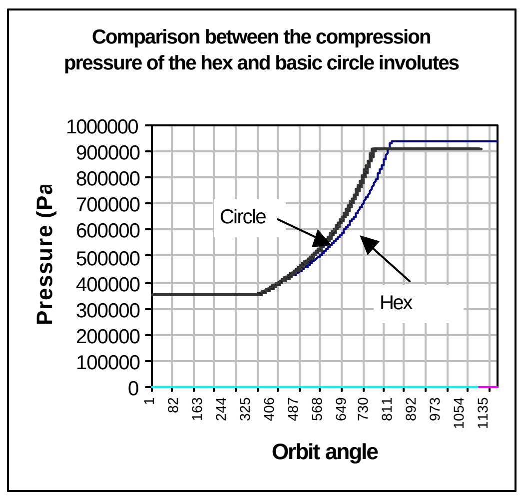


Fig. 9 Volumes and compression pressures for hexagonal and basic circle