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Optimization Technique for the Geometry of Twin Screw Cryogenic Extruder

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Abstract

Production of electricity without generating hazardous element to the atmosphere, in an efficient way, is one of the biggest requirements of the today's world. Fusion of hydrogen isotopes gives tremendous amount of energy which can be utilized in power stations. Fusion takes place inside a machine called Tokamak. Tokamak facilitates the fusion to be taken place continuously in a controlled manner. Simultaneously we need to provide continuous hydrogen pellets inside the tokamak to be fused in only solid form. And for this purpose, screw extrusion is to be found the best option. In this paper a technique for geometry optimization is discussed. And for that constraints are (1): Throughput rate is fixed (2): Limitation on upper range of RPM. Here a method is given for selection of one geometrical parameters which is empirically connected to others, while taking care of constrains

Keywords: Screw Extruder, Twin Screw, Screw Geometry, Optimization

I. INTRODUCTION

For the purpose of hydrogen fuelling to the tokamak, screw extrusion is to be found the best option. Now one can optimize the geometry of the screws. Here one methodology is adopted for the calculation of the geometrical parameters. According to this methodology and constraints on the system, an attempt to optimize screw dimensions is carried out.

II. DESIGN METHODOLOGY OF TWIN SCREW

There are some parameters that must be calculated before going towards the optimization of the twin screw cryogenic extruder. Which are D=screw diameter, d=inner diameter, W=flight width, H=flight depth, P=pitch, Φ=helix angle, L=total length, S=lead/pitch, α = intermesh angle.

A. *Intermeshed Region:*

In the figure below, the top view of intermeshed region is shown. From that the relation between D=screw diameter, d=inner diameter, H=flight depth and α = intermesh angle is established.

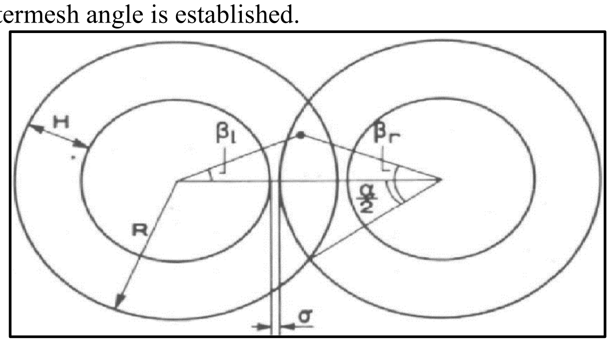

Fig. 1: Top View of Intermeshed Region [I]

Now from the geometry we get[i]

$$\tan\left(\frac{\alpha}{2}\right) = \frac{\sqrt{RH - \frac{H^2}{4}}}{R - {}^{H}/_{2}}$$

So,

$$\alpha = 2\tan^{-1}\left[\frac{\sqrt{RH - \frac{H^2}{4}}}{R - {}^{H}/_{2}}\right]$$

B. C - Section Chamber:

Now we need to find the C – chamber volume shown in fig: [i]

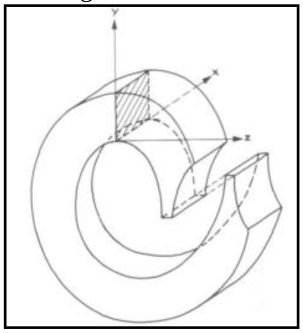

Fig. 2: C – Chamber [i]

The volume calculation of a c-chamber is significant, because their volume, in turn, will allow an estimate of the total amount of material in the extruder. the c-chamber volume is calculated by considering the axial half volume of the barrel and subtracting from it the volume of a single screw root , its thread , and the half of the region where the screw threads intermesh.

The volume of one barrel half minus half of the intermeshing region, V1, is given by Equation 2, where α is defined in above equation. The derivations of these equations are provided in appendix

Consider three different volumes to simplify calculations: [i]

- V1=the volume of the one barrel half over one pitch length

$$V_1 = \left[\left(\pi - \frac{\alpha}{2}\right)R^2 - \left(R - \frac{H}{2}\right)\sqrt{RH - \frac{H^2}{4}}\right]S \qquad (2)$$

- The volume of the screw root: [i]

$$V_2 = \Pi(R - H)^2 \qquad (3)$$

The volume of the screw threads, V3 is found by equation. Note that B is the thickness of the threads, which is not necessarily constant, could be a function of r. For this application, though, B is essentially constant and will be treated as such.

- V3 = Volume of one screw flight: [i]

$$V_3 = \int_{R-H}^{R} b(r)\, 2\Pi r dr$$

B (r) is the width of the flight in axial direction at a radius r. For straight sided screws b(r) can be approximated by

$b(r) = B + 2(R - r)\tan\Psi$

- So V3 now reduced to

$$V_3 = 2\Pi\left[\left(RH - \frac{H^2}{4}\right)B + \left(RH^2 - \frac{2}{3}H^3\right)\tan\Psi\right] \qquad (4)$$

- Now Total C-Chamber Volume[i]:

$$V_C = V_1 - V_2 - V_3 \qquad (5)$$

- Number of turns

$$N = \frac{\text{totallengthofscrew}}{\text{leadofthescrew}} = \frac{L}{S} \qquad (6)$$

- Total volume within the extruder:

$$V = 2 * N * V_c \qquad (7)$$

Where n is the numbers of turns of the threads, and the factor of 2 comes from the fact that there are two halves of the system. The volumetric flow rate of the system can be approximate as the screw rotation rate (n) times the volume of one screw turn.

$$Q = 2 * V_c * n \qquad (8)$$

- The Rpm of the Screw:

One revolution makes one V_c volume to come out through the extruder, so

$$RPS = \frac{Q}{2V_C} \qquad (9)$$

$$RPM = \frac{Q}{2V_C} * 60 = n \qquad (10)$$

And mass flow rate

$$m = \rho * Q = \rho * 2 * V_c * n \qquad (11)$$

III. OPTIMIZATION METHOD

We have design methodology of screw extruder based on plastic extrusion technique and its literature. Accordingly we need to analyze the effect of change of value of different parameters on different other parameters. Now according to design methodology, each geometrical parameter has influence on throughput. So each parameter should be taken care of, so that throughput remains as per requirement and other parameters are in feasible range. For this, some parameters must be fixed before optimization as base parameters which will not be changed during whole procedure. Some should be connected by empirical relations and some should be altered to check its effect on output.

So first we are fixing the helix angle as 17.7° as it is commonly used in plastic extrusion industry. Also we are fixing the screw length as 150 mm because we want a compact extruder. Now pitch and hence no. of turns are fixed by simple geometrical sense. Now channel width is related to pitch by a factor of 1.667 which commonly sued in plastic industry.

Now we should fix the empirical relation between inner and outer diameter of the screw. And we are choosing it as 1.4 factors to maintain a space for operation of gear.

Now for cryo extruder we have limited range of Diameters because

1. Very small diameter cannot provide enough throughput in RPM (below) range, also with decreasing diameter, center line distance decreases which is limited by gears connecting two screw shafts.
2. Larger diameter will spoil the quality of solid due to large thermal gradient from material in connect with barrel and material at channel depth.

Also we have constraints on higher limit of RPM due to heat generation as 15 RPM. Because higher RPM leads to high heat generation due to friction and so longer length of screw is required to achieve required cooling of extrudate material. And lower RPM will decrease the throughput directly which cannot fulfil the requirement.

So we need to check variations of decreasing diameter on RPM for required throughput.

– Requirement of the extruder is

Table - 2

pallet diameter	*5*	*mm*
pallet length	*5*	*mm*
pallet frequency	*10*	*Hz*
Volume flow rate	*~1*	*CC/sec*
Mass flow rate	*~1.6*	*g/sec*

Now our throughput is fixed and for constant throughput, a graph of RPM vs. D_o can be plotted.

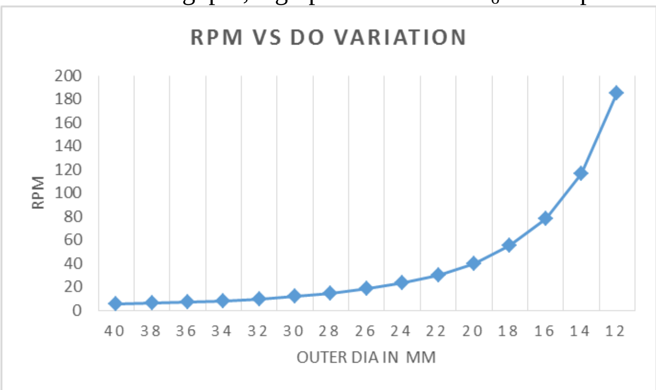

Fig. 3: RPM VS DO VARIATION

As we can see from the graph the RPM must be increased to compansate the reduction in D_o. For more information we can connect V_c, RPM and D_o in a single graph to analyse it for ±10%, ±20% throughput. Here V_c will decrease with decreasing diameter and RPM should be increased to compansate it.
The graph shows the combined effect of all three parameters

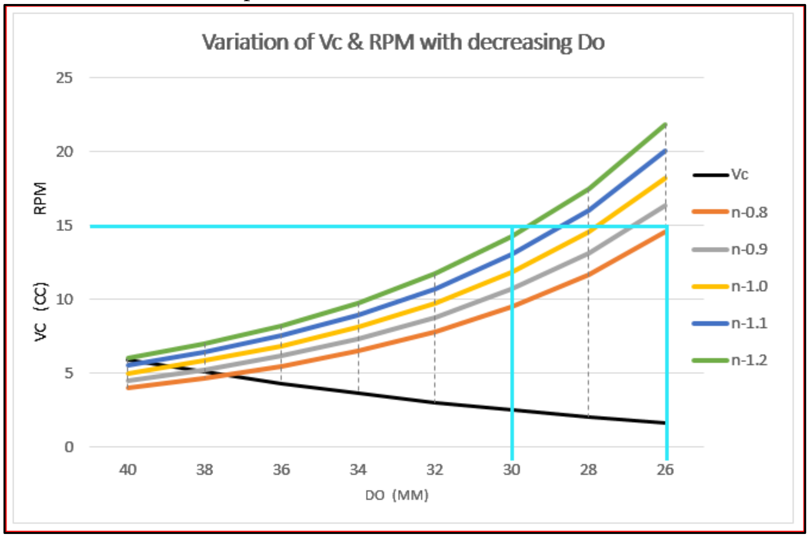

Fig. 4: Variation of Vc & RPM with Decreasing Do

Now from this graph we can analyse that for the diameter range of 30 to 26 mm the feasible RPM (below 15) is achieved which can be considered as design values. For 100% throughput, 28 mm screw diameter is near to 15 RPM. So it can be used as design Diameter - Do for this methodology.
Now decided dimensions are

- D = screw diameter = 28 mm
- d = inner diameter = D/1.4 = 20 mm
- W = flight width=1/1.6667 * P = 8 mm
- H = flight depth = (D-d) / 2 = 4 mm
- P = pitch = 1d = 20 mm (square)
- Φ = helix angle = 17.7° (normally)
- L = total length = (5 d to 10 d) = 150 mm
- S = lead = d = 20 mm
- α = intermesh angle = 17.7 °

With this dimensions C – section Volume, RPM, mass flow rate of extrudate, volume flow rate of extrudate can be calculated. The calculated results are shown in table below.

IV. RESULT FROM ABOVE METHODOLOGY AND OPTIMIZATION

Table -3
RESULT FROM ABOVE METHODOLOGY AND OPTIMIZATION

Parameters	*Description*	*Unit*	*Value*
S	*Axial length of one thread rotation*	*mm*	*20*
α	*angle of intermesh region*	*degree*	*62.01*
R	*Outer Screw Radius*	*mm*	*14*
D	*Outer Screw Diameter*	*mm*	*28*
H	*Channel Depth*	*mm*	*4*
B	*Channel width*	*mm*	*12*
V_c	*Volume of a C chamber*	cm^3	*2.02*

V	*Total volume for material within extruder*	cm^3	*30.31*
N	*Number of turns of the screw thread*		*7.5*
Q	*Volume Flow Rate*	cm^3/s	*0.9815*
n	*Screw rotation Speed*	*rpm*	*14.57*
ρ_{solid}	*Solid argon density*	kg/m^3	*1600*
m	*Material mass flow rate*	*kg/s*	*1.57E-03*

V. CONCLUDING REMARKS

- The variation in Inner and outer diameter has great impact on RPM and C – section Volume.
- For optimum RPM and fixed Throughput requirement, very narrow range of Diameter.
- By following this methodology, we can select optimum Diameter.
- For selected dimensions, RPM is nearly 15 for Volume flow rate of nearly 1 cc / sec, which can be considered as feasible.

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