



**Ain Shams University
Faculty of Engineering
Design and Production Engineering Department**

Design of Plastic Machine Screws using FEA

By

Ibrahim Fikry Gaber Mohamed

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A Thesis Submitted in Partial Fulfilment for the Requirements of the
Degree of Master of Science in Mechanical Engineering

Under the supervision of:

Prof. Samy Jimmy Ebeid

**Professor of Design and Production
Engineering
Ain Shams University**

**Dr. Eng. Wagdy El- Desouki
Abdel-Ghany**

**Associate Professor of Design and Production
Engineering
Ain Shams University**

Cairo, 2015

Curriculum vitae

Name: Ibrahim Fikry Gaber Mohamed

Birth Date: 30-11-1988

Degree: Bachelor Degree in Mechanical Engineering, Design and Production Section, Ain Shams University, July 2010.

Current Job: Teaching Assistant, Design and Production Engineering Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

STATEMENT

This thesis is submitted in partial fulfilment for the degree of Master of Science in design and production engineering, to the faculty of engineering, Ain Shams University.

The work included in this thesis was carried out by the author, at the Design and Production Engineering Department, Faculty of Engineering, Ain Shams University.

No Part of this thesis has been submitted for degree or qualification at any other universities.

Signature

Ibrahim Fikry Gaber Mohamed Salama

Date:

Board of Supervisors

The undersigned certify that they have read and recommended to the Faculty of Engineering, Ain Shams University, for acceptance a thesis entitled "**Design of plastic machine Screws using FEA**", submitted by **Ibrahim Fikry Gaber Mohammed**, in Partial Fulfilment for the Requirements of the Degree of Master of Science in Mechanical Engineering.

1. Samy Jimmy Ebeid

Professor, Design and Production Engineering department,
Faculty of Engineering,
Ain Shams University.

2. Wagdy El-Desouki Abdel-Ghany

Associate Professor, Design and Production Engineering department,
Faculty of Engineering,
Ain Shams University.

Date (/ /)

Examiners Committee

The undersigned certify that they have read and recommended to the Faculty of Engineering, Ain Shams University, for acceptance a thesis entitled " **Design of plastic machine Screws using FEA** ", submitted by **Ibrahim Fikry Gaber Mohammed**, in Partial Fulfilment for the Requirements of the Degree of Master of Science in Mechanical Engineering.

Signature

1. Nabil Abdel Hamid Mohamed Gadallah

Professor, Manufacturing Engineering and Production
Technology Department.
Modern Academy for Engineering and Technology.

2. Hesham Ali Abdel-Hamed Senbel

Professor, Head of Design and Production Department.
Faculty of Engineering.
Ain shams University.

3. Samy Jimmy Ebeid

Professor, Design and Production Department.
Faculty of Engineering.
Ain Shams University.

Date (/ /)

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Abstract

Many theoretical, experimental, and simulation studies have already described the polymer behavior in Extrusion process focusing on the polymer flow inside the barrel. However, the mechanical behavior of the screw shaft itself during extrusion does not draw much attention, although non proper design and selection of this device, which is present in large part of industrial processes, could mean poor performances, excessive power, severe wear of screw and degradation of the conveyed material.

The present work aims to investigate the performance of various types of screw under different working conditions. Finite element analysis is used to master a technique to evaluate the radial displacement of the used screw, while analytical solution is used to clearly describe the polymer behaviour affecting the proposed screw. The screw parameters are its feed zone length and compression zone length, while the axial pressure, temperature profiles and screw speed are the main parameters considered in processing the desired polymer.

The pressure profile along the length of the extruder reaches a maximum close to the end of the compression section of the screw. Sharp pressure peaks occurred at low speeds for the traditional screw case, while being at the high speed range for the rapid compression screw case. The temperature profile along the screw is affected by the set temperature of the metering section heater. The minimum displacement occurred at the metering zone, while the maximum displacement occurred at the feed zone moving to the compression zone for traditional screw. Pressure has little effect on the screw displacement ranging from 5 % to 10 %, while temperature has the major contribution in screw displacement. Screw displacement could be decreased by screw cooling of the feed section, reduced temperatures in the metering section, and increasing clearance in the feed throat region.

Keywords: Extrusion, Single screw extruder, Screw Design, Finite element analysis, Screw displacement.

Summary

Single screw extruders come in many different designs. Traditional and rapid compression screws have been chosen for its low cost, straightforward design, reliability and favorable performance to cost ratio compared to other screw designs. Therefore, investigation and evaluation of the parameters that affect the performance of the proposed screw were performed in the present work. The implemented methodology can be further applied to other extruder types. The proposed development incorporates the following sequence:

- 1- Estimation of screw performance for the low density polyethylene (LDPE) being extruded, where pressure and temperature along the screw were predicted.
- 2- Modeling of the two types of the screw using Autodesk Inventor 2012.
- 3- Using Finite element method to calculate the screw radial displacement under the working conditions using Ansys 15.0.

The following points summarize each of the above developed activities and demonstrate the benefits gained from each:

- 1- A mathematical model has been used and its behavior was verified using published experimental results for the traditional screw design to calculate the pressure profile along the screw. The results of simulating the proposed screw indicated that by means of changing the type of screw and changing the processing conditions. The pressure profile along the length of the extruder reaches a maximum close to the end of the compression section of the screw. Sharp pressure peaks occurred at low speeds for the traditional screw case, while being at the high speed range for the rapid compression screw case. Different dies almost have no effect on pressure profile along the screw, but rather affect the head pressure.

- 2- Three heaters with different temperature sets have been used to note the distribution of temperature along the screw. The temperature of the screw is affected by barrel temperature at the zone over the metering channel. Screw rotational speed has a little effect on the screw axial temperature profile.
- 3- Two screws with the same length to diameter ratio, compression ratio and screw material but different in the length of the feed and compression zones were used to predict the radial displacement under changing the pressure and temperature in the axial direction.
- 4- The study of traditional screw shows that by mean of increasing temperature, the flights subjected to maximum displacement increased with the same radial displacement magnitude. The maximum displacement occurred at feed and compression zones with value of 0.252 mm while minimum displacement occurred at metering zone with value of 0.024 mm. The rapid compression screw has more tendencies to increase the magnitude of displacement on opposite to traditional screw when changing heater temperature with maximum value of 0.773 mm but with the same flights subjected to maximum displacement. The pressure for both screws has little effect on the screw displacement which didn't exceed 10 % of the total screw displacement.
- 5- After investigating the mechanical model it was found that, screw cooling of the feed section is needed to overcome the binding of screw in this section, reduced temperatures in the metering section and increasing clearance in the feed throat region are needed to reduce the screw displacement.

Nomenclature

Symbol	Description	Units
b	Temperature Coefficient	1/ °C
C _p	Polymer specific heat	J/Kg. °C
C _R	Compression Ratio	-
D	Screw diameter	mm
$\bar{D}_b$	Inside barrel diameter	mm
D _s	Screw root diameter	mm
e	Width of the Flights	mm
E	Modulus of elasticity	MPa
F ^a	Total applied load vector	N
f _b	Dynamic coefficient of friction at barrel surface	-
F _d	Shape factor for drag flow	-
F _p	Shape factor for pressure flow	-
F ^r	Reaction load vector	N
f _s	Dynamic coefficient of friction at screw surface	-
g	Gravitational acceleration	m/s ²
H	Screw channel depth	mm
H _f	Channel depth at feed section	mm
H _m	Channel depth at metering section	mm
K	Lateral stress ratio	-
K	Total stiffness matrix	N/m
K _e	Element stiffness matrix	N/m
L	Screw Lead	mm
l	Axial distance	mm
L _C	Compression zone length	mm
L _d	Die Length	mm
LDPE	Low Density polyethylene	
L _f	Feed zone length	mm
L _m	Metering zone length	mm
m _o	Consistency	Pa.s ⁿ
N	Screw rotational speed	rev/min
n	Power law index	-
P	Generated polymer pressure	Pa

P_o	Starting pressure	Pa
Q	Volumetric flow rate	mm^3/min
Q_d	Volumetric Drag flow	mm^3/min
Q_l	Volumetric Leakage flow	mm^3/min
Q_p	Volumetric Pressure flow	mm^3/min
R	Capillary die radius	mm
T	Channel width	mm
T_b	Barrel temperature	$^{\circ}\text{C}$
T_m	Melting temperature of polymer	$^{\circ}\text{C}$
T_s	Screw temperature	$^{\circ}\text{C}$
T_{so}	Pellets temperature	$^{\circ}\text{C}$
U	Nodal displacement vector	-
V_b	Tangential barrel velocity	mm/min
V_d	Moving Plate Velocity	mm/min
V_x	Cross channel velocity	mm/min
V_z	Down channel velocity	mm/min
X_o	Solid bed width	mm
Z	Element down channel length	-
$\dot{\gamma}$	Shear rate	1/s
α	Thermal conductivity of molten polymer	W/m. $^{\circ}\text{C}$
δ	Flight radial clearance	mm
δ_o	Melt film thickness	mm
Θ	Solid conveying angle	Degree
λ	Heat of fusion	J/Kg
ν	Poisson ratio	-
ρ_B	Bulk density	Kg/m^3
ρ_m	Molten polymer density	Kg/m^3
ρ_s	Solid polymer density	Kg/m^3
σ_{ut}	Ultimate strength	MPa
σ_y	Yield strength	MPa
τ	Fluid shear stress	Pa
Ω	Local melting flux	$\text{Kg}/\text{m}^2.\text{s}$
ϕ	Helix angle	Degree
η	Viscosity	Pa.s

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