Design and fabrication of a transmission mechanism arm for rotational molding

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Abstract: Compared with blow molding and thermoforming technology, rotary die technology has many advantages for manufacturing hollow plastic products. The purpose of this paper is to compute and design the transmission crank mechanism of the rotary die machine. The authors chose a reasonable solution to design the experimental model to produce flower pots with dimensions of 1000 x 400 x 400 mm. The principle diagram and the dynamic diagram of the machine are presented. Computation and design of main clusters and hand fabrication of the rotary die machine are investigated. The model of the transmission crank mechanism is fabricated to verify the validity of the proposed model.

Key words: Transmission crank, thermal forming, Additive interactions; Antioxidants; Rotational Molding.

1. Introduction
Rotational molding, also known as rotocasting or rotomolding, is a method of fabricating hollow plastic products with low pressure, high temperature. Many centuries ago, it was known the method of coating a layer of material inside a rotating mold to create products, but it was not until the 1940s of the twentieth century that it was recognized as french rotary molds for plastic products. Since then, scientists have embarked on the research and design process of the first rotary die machine models. In particular, some countries have developed quite strongly in this field such as: Italy (Rotomachinery Group), Brazil (Rotoline company), India (Naroto firm), etc.

Rotational molding is a highly competitive method compared to methods such as blow molding and injection molding in the production of hollow plastic products. Rotational molding network offers more economic value when plastic products require no residual stress, wide size range, uniform thickness, complex shape and high detail.

Currently in Vietnam, there are not many studies on the topic "Research and design of rotary molding machine". This is a relatively new research direction in Vietnam, opening up an overview of Rotational molding. Since then, proposing the manufacturing process to meet the needs of the market, bringing new development directions for businesses, replacing imported products, this is also the urgency of the topic.
2. Analysis and selection of plan

2.1 The Process
During the molding process, the plastic powder is heated and melted in the mold cavity, and the shape, size, and surface of the product are copied from the inner surface of the mold. During heating and cooling, the mold rotates in two axes perpendicular to each other. The most common heating is done in a heating furnace, convection with a stream of hot air, and the plastic melts, covering the entire inner surface of the mold, followed by cooling (with air, mist or water), lower the temperature to allow the resin to solidify. Finally, remove the mold and take the product (Figure 1).

![Figure 1. Principle of rotational molding.](image)

2.2 Analysis and selection of plans
Rotating Mold Technology products have a very wide range of volumes from 0.05 liters to over 10,000 liters, so the rotary die systems are very diverse. The basic common feature of this process is that molds need to be rotated, heated, and cooled. Depending on product size, productivity, allowable area, heating and cooling characteristics, there are different rotary die systems, which are commonly used today as shown in Figure 2.

![Figure 2. Types of Rotational Molding Machines, courtesy of Polivinil, Italy- The Queen’s University, Belfast](image)
After learning about the product to be manufactured, the product’s size parameters, materials, Rotational molding as well as the principle, operation method, scope of use of the machines used in mold technology turned. We choose the independent rotary arm molding machine to design the machine for making flower pots products.

3. Design calculation of mold driving system
After analyzing the product, the principle of the rotational mold technology, the design team evaluates and chooses a suitable plan for the flower pot product. The following is the drive diagram of the designed rotary die system (Figure 3).

![Drive diagram of rotary die system](image)

**Figure 3.** Drive diagram of rotary die system

3.1. Calculation of the drive on the auxiliary shaft
The drive on the auxiliary shaft is shown on Figure 4 below.

![Drive diagram of auxiliary shaft](image)

**Figure 4.** Drive diagram of auxiliary shaft

3.1.1. Select the engine and distribute the gear ratio
Based on the DRS catalog, the design team chose the K67 modular single-phase motor with the following parameters: $P_{dc} = 1.1 \text{ kW}; n_{dc} = 20 \text{ rpm}$. 
Table 1. Engine size K67 DRS 80M4.

| CODE      | AC | AD  | ADS | L   | LS  | LB  | LBS |
|-----------|----|-----|-----|-----|-----|-----|-----|
| DR80M     | 156| 128 | 139 | 530 | 611 | 261 | 342 |

Based on the table 1, we calculate the number of revolutions, power and torque on the axes (Table 2):

Table 2. Auxiliary shaft characteristics.

| Parameter               | Axes                  | 1          | 2          | 3          |
|-------------------------|-----------------------|------------|------------|------------|
| Power P (kW)            | geared motor          | 0.64       | 0.49       | 0.44       | 0.41       |
| Transmission ratio u    |                       | 2          | 1          | 1          |            |
| Revolutions n (rpm)     |                       | 20         | 10         | 10         | 10         |
| Torque T (Nmm)          |                       | 305600     | 467950     | 420200     | 391550     |

3.1.2. Calculate the drive on the auxiliary shaft

**Axis 1**

Material selection: Improved 45 steel with $\sigma_b = 600\text{MPa}$; $\tau = 20\text{ MPa}$

Diameter of shaft determined by torque:

$$d \geq \left( \frac{T}{0.2[\tau]} \right)^{1/3} = \left( \frac{467950}{0.2 \times 20} \right)^{1/3} = 48.9\text{mm} \quad (1)$$

Analysis of force and torque on the shaft determines the dangerous section at B. Shaft diameter at B:

$$d \geq \left( \frac{M_{\text{tot}}}{0.2[\sigma]} \right)^{1/3} = \left( \frac{700619}{0.1 \times 85} \right)^{1/3} = 43.52\text{mm} \quad (2)$$

According to the diameter standard at the sections: $d_A = d_D = 42\text{ mm}$; $d_B = d_C = 45\text{ mm}$.

**Axis 2**

Material Selection: Improved 45 steel with $\sigma_b = 600\text{MPa}$; $\tau = 20\text{ MPa}$.

The shaft diameter is determined by the torque:

$$d \geq \left( \frac{T}{0.2[\tau]} \right)^{1/3} = \left( \frac{420200}{0.2 \times 20} \right)^{1/3} = 47.2\text{mm} \quad (3)$$

**Figure 5.** Force exerted on axis 1.
Analysis of force and torque on the shaft determines the dangerous section at F. The shaft diameter at F
\[ d \geq \left( \frac{M_{ed}}{0.1[\sigma]} \right)^{1/3} = \left( \frac{1137330}{0.1 \times 85} \right)^{1/3} = 49.6 \text{ mm} \quad (4) \]

According to the diameter standard at the sections: \( d_F = d_G = 50 \) mm; \( d_E = d_H = 45 \) mm.

**Axis 3**
Material Selection: improved 45 steel with \( b \sigma_b = 600 \text{MPa}; \tau = 20 \text{ MPa}.\]

Calculating similar to the above two axes, the design team determined the diameter of axis 3 at the sections: \( d_I = d_K = d_L = 50 \) mm; \( d_M = 45 \) mm

3.2. *Calculate the drive on the main shaft* (Figure 8)
3.2.1. Select the engine and distribute the gear ratio
Based on the DRS catalog, we chose the K67 modular single-phase motor with the following parameters: 
\[ P_{dc} = 1.5 \text{ kW}; n_{dc} = 16 \text{ rpm}. \]

| CODE    | AC | AD | ADS | L   | LS  | LB  | LBS |
|---------|----|----|-----|-----|-----|-----|-----|
| DR90M   | 179| 140| 150 | 532 | 611 | 261 | 342 |

Based on the table 3, we calculate the number of revolutions, power and torque on the axes (table 4):

| Parameter                | Axes        | geared motor | 4 |
|--------------------------|-------------|--------------|---|
| Power P (kW)             | 1           | 0.96         |   |
| Transmission ratio u     | 2           |              |   |
| Revolutions n (rpm)      | 16          | 8            |   |
| Torque T (Nmm)           | 596875      | 1146000      |   |

3.2.2. Calculation of cylindrical gear transmission
Based on the calculation results and look up the table, we chose the gear transmission, chain with the following basic parameters (Table 5)

| Parameters                        | value                             |
|-----------------------------------|-----------------------------------|
| Spindle distance aw               | 150 mm                            |
| Module                            | m = 2 mm                          |
| The width of the rim b₇ and b₈    | b₇ = 60 mm; b₈ = 50 mm             |
| Ratio                             | u = 2                             |
| Number of teeth Z₇ and Z₈         | Z₇ = 50; Z₈ = 100                  |
| Shift coefficient X₇ and X₈        | X₇ = 0; X₈ = 0                     |
| Diameter of divider d₇            | d₇ = 100 mm; d₈ = 200 m            |

3.2.3. Design calculation of main shaft
Material Selection: Improved 45 steel with \( \sigma_b = 600 \text{ MPa}; \tau = 20 \text{ MPa}. \)

The shaft diameter is determined by the torque:

\[
d \geq \left( \frac{7}{0.2[\tau]} \right)^{1/3} = \left( \frac{1146000}{0.2 \times 20} \right)^{1/3} = 66 \text{ mm} \quad (5)
\]

Analysis of force and torque on the shaft determines the dangerous section at P. Shaft diameter at P:

\[
d \geq \left( \frac{M_{td}}{0.1[\sigma]} \right)^{1/3} = \left( \frac{3028730}{0.1 \times 85} \right)^{1/3} = 77.5 \text{ mm} \quad (6)
\]

According to the diameter standard at the sections: \( d_P = d_Q = 100 \text{ mm}; d_O = 110 \text{ mm}; d_N = 115 \text{ mm} \)

3.3. Durability and displacement test of some important details
Critical parts, susceptible to destructive deformation, should be simulated to check for the following properties: Ensure the deformation is within the allowable range, thereby ensuring the working requirements of the parts. Ensure that the stress generated by the force exerted on the part does not exceed the strength limit of steel \( \sigma_b < 598 \text{ MPa} \) (TCVN 8301).
3.3.1. Large shaft details (Figure 10)
Input parameters: m = 40.68 kg; steel C45, V = 0.0051772 m$^3$, F = 2452 N

4. Results
The meshing and simulation results are shown on Figure 11.

![Figure 9. Force exerted on axis 4.](image)

![Figure 10. Placing of mounting and force on part.](image)

![Figure 11. Results of stress analysis (a) and strain (b) product on large shaft](image)

| Stress | Deformation | The analytical results show |
|--------|-------------|-----------------------------|
| Min : 4.2618 $\times 10^9$ N/mm$^2$ | Min: 0 mm | Part displacement is relatively small 0.02 mm |
| Max : 12.86 N/mm$^2$ | Max: 0.0286 mm | Ensure the surface of the part 12.85 MPa $<$ 598 Mpa |
The horizontal part is shown on Figure 12.

*Input parameters:* \( m = 46.37 \text{ kg}; \) steel C45; \( V = 0.00590125 \text{ m}^3; \) \( F = 1776 \text{ N} \)

![Figure 12. Placing mount and force on part](image)

The meshing and simulation results of the part is shown on Figure 13.

![Figure 13. Results of stress (a) and deformation (b) analysis on the details](image)

| Stress | Deformation | The analytical results show |
|--------|-------------|-----------------------------|
| Min : 9.10462 \( \times 10^{-5} \text{ N/mm}^2 \) | Min: 0 mm | Part displacement is relatively small 0.019 mm |
| Max : 5.264 N/mm\(^2\) | Max: 0.0194604 mm | Ensure the surface of the part 12.85 MPa <598 MPa |

The design team calculated, designed and manufactured the rotary die machine with the following main technical parameters (Table 8).

| Parameters | Result |
|------------|--------|
| Spindle rotation speed | 8 rpm |
| Auxiliary shaft rotation speed | 10 rpm |
| Productivity | 26 products / 8 hours |
| Product size | 1000 x 400 x 400 mm |
Figure 14. Photos of the actual fabricated machine.

5. Conclusion
Rotational molding is a highly competitive method compared to methods such as blow molding and injection molding in the production of hollow plastic products. The authors studied the set-up of the drive diagram of the rotary die system. In addition, the analysis and calculation of the force acting on the drive axes are also presented in this study. We designed and manufactured the rotary die machine a rotating mold for flower pots products with dimensions 1000x400x400 mm. The machine can change its two-axis speed, with a productivity of 26 products / 8 hours. However, it is necessary to continue with in-depth studies such as the effects of technological parameters on product quality in terms of size and sample strength on different materials, and researches to improve accuracy of product.

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