The Application of Nonlinear Programming in Industrial Product Design

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Abstract

Nonlinear programming is a powerful tool to find the optimal size of the design process, it can save the cost of production and processing under the premise to meet user requirements. In this work, the rising side table is used as the study objective, and nonlinear programming method is used to facilitate processing of the objective function, the geometric relationship between the desktop and the legs of constraints, to build the nonlinear programming model. Calculated by MATLAB to obtain the optimal processing program.It is concluded that, Given height of 70cm and 80cm diameter round table, the optimal processing program is flat length 158cm, width 79.9cm, thickness 3cm, leg width 4.7cm, legs number 17.

Keywords

Nonlinear programming ; the rising folding table; size processing design; the optimal design; the product design.

1. Introduction

The product design is closely related to life style, and the industrial product design is the product of the industrial age, which is much more closely contact with mechanization, standardization and mass production [1-3].In industrial product design, whether the product is practical, beautiful, innovative, man-machine and sustainability or not is the design problems should be considered, for the enterprise, how to save material and processing is convenient, are also what they care about. In product design and mold production, we often judge according to our subjective experience, which adds to the cost of production and elongate the production cycle. With the development of computer technology, and now the design cycle and design scheme of enterprise are proposed to be better and higher requirements are put forward. Taking the Rising Side Table as the research object, we take the considering standard of customers and the convenience in processing into consideration, and obtain the best design scheme.

2. The introduction of nonlinear programming method

Objective function is nonlinear programming with nonlinear constraints or mathematical programming, which is an important branch of operational research. Nonlinear programming is a new discipline beginning to form in the 1950s.Nonlinear programming are widely used in engineering, management, economy, scientific research, military and so on, and provides a powerful tool for the optimal design. In the field of industrial design, often need to be considered in the design of multiple targets, the targets are generally nonlinear. Introduced in the design of nonlinear programming, can be quantitative objective conditions, to obtain the optimal solution.

3. The optimum design of flat folding table size processing scheme

Dutch designer Robert van Embraces' famous flat folding table is the Gospel of small family homes, which has some clever strips at the middle of the table. When needed, the table can be folded to form a stable triangle, when not needed, it can be completely flat tucked into bed.

Fig.1 The deployment process of the rising side table

The Designer cut board into several sticks, and retain the central desktop. So the board remained presents the serrated circular board. Then all the wood and the desktop are connected with special hinge, and the wood sticks are connected with a chain into a string.

When we use the table, we can push the sticks on both sides and pull the whole table, then the table can be set up. When we don't use the table, the table can be fold into a slab and received in once corner. So the table gas has the very high practical [8 ~11].

The design of folding table should has good stability, easily process, and has minimum material. For any given requirements of the folding table, we should obtain the specific parameters of the table, such as the height and diameter of the table. In this paper, we discuss the situation where the height of the table is 70cm, and the diameter of the table is 80cm and determine the specific parameters of the table.

4. The establishment of a nonlinear programming model

4.1 nonlinear programming model to make materials most province

According to processing requirements, we can draw the following conclusion: the stability of the folding table is supported by four legs; material is determined by the width of each legs; convenience is determined by the location of the slot. So according to the given height of the folding table and circular diameter, we take the convenience as the objective function, and the geometric relationship between desktop and sticks as constraint condition to establish the nonlinear programming mode.

We assume that the radius of the table is R, the width of the table leg is d, the amount of the table legs is m, and number of the table legs from the outside piece table leg to the middle legs is $1,2,\cdots,\frac{m}{2}$, so there is the constraint relations between the three parameters as follows:

$$m=\begin{cases}\frac{2R}{d}-1 & , \frac{2\mathrm{R}}{\mathrm{d}}\text{is an integer}\\ [\frac{2R}{d}] & , \frac{2\mathrm{R}}{\mathrm{d}}\text{is not an integer}\end{cases}$$

When $\frac{2\mathrm{R}}{\mathrm{d}}$ is an integer , we can know that the outside leg of the desktop after folding is tangent with the circle. In order to unfold the table easily, we remove a piece of wood and find that the end of every table leg can form a circle.When $\frac{2\mathrm{R}}{\mathrm{d}}$ is not an integer, we rounded it down, namely $[\frac{2R}{d}]$. We also connected the end of every table leg, and it can form a circle.

We assume that the distance between the outside table leg and the diameter of the table is k, and obtain the relationship between them according to the Pythagorean theory:

$$k=\sqrt{R^2-(\frac{m}{2}d)^2}$$

According to the knowledge of structural mechanics can be known, to make the folding table stability, we should take the surface formed by four supporting legs square, namely:

$$\sqrt{(\frac{a}{2}-k)^2-(h-c)^2}+k=\frac{m}{2}d$$

In this formula, a is the length of the table, c is the thickness of the table, h is the height of the table.

If we take the minimum volume as the aim, we can get the following formula:

$b=md$

In this formula, b is the width of the table, d is the width of the table leg.

Because the thickness of the table has little importance than the length and the width of the material, and the common thickness of the table in the market is 3cm, 5cm, 8cm, we assume that the thickness of the table is 3cm and establish the nonlinear programming model as follows:

$$\min f=abc$$

$$s.t.\begin{cases} k=\sqrt{R^2-(\frac{m}{2}d)^2} \\ m=\begin{cases} \frac{2R}{d}-1, & \frac{2R}{d}\text{ is an integer} \\ [\frac{2R}{d}] & \frac{2R}{d}\text{ is not an integer} \end{cases} \\ \sqrt{(\frac{a}{2}-k)^2-(h-c)^2}+k=\frac{m}{2}d \\ b=md \\ d>0 \\ c=3 \end{cases}$$

Based on the above nonlinear programming model, for any requirement about the height and diameter of the table, we can get specific information to make the folding table by using MATLAB.

4.2 nonlinear programming model to make process convenient

The processing convenience is mainly affected by the length of the slot. We assume that b_i is the distance between the legs of the table and the diameter of the circular table and the number of the table leg from outside is $1,2,\cdots,\frac{m}{2}$. So we can get the following formula:

$$b_i=\sqrt{R^2-[(\frac{m}{2}-i)d]^2}$$

In this formula, $i=1,2,\cdots,[\frac{m}{2}]$.

If we assume that f_i is the length of the table leg numbered I, we can get the following formula:

$$f_i=\frac{m}{2}-b_i$$

When the table is unfolded, the distance between the rebar and the hinge is s_{i1}, among them $i1 = 1,2,\cdots,[\frac{m}{2}]$. When the table is folded, the distance between the rebar and the hinge is s_{i2}, among them

$$. \ i2 = 1,2,\cdots,[\frac{m}{2}]$$

The D-value between these distances is the length of the slot: $s_i = s_{i2} - s_{i1}$. If the scale of the distance between the rebar and the table leg in the length of the table leg is α, we can get the following formula:

$$s_{i1} = f_i - \alpha \cdot f_i$$

$$s_{i2} = \sqrt{[(1-\alpha) f_i]^2 + (b_i - k)^2 - 2(b_i - k)(1-\alpha) f_1 \cos\theta_1}$$

In the formula, the θ is the angle between the table leg and the floor, which can be shown as following:

$$\theta_1 = \arcsin(\frac{2(h-c)}{a-2k})$$

From a practical point of view, the length of the empty slot should be less than the distance between the start point of the slot and the end of the table leg. So if we take that we make the stability best and Therefore, on the basis of the best stability and less material, we take the minimize the length of the target slot as aim and establish the nonlinear programming model. The formula is shown as follows:

$$\min f = \sum_{i=1}^{\frac{m}{2}} (s_{i2} - s_{i1})$$

$$s.t. \begin{cases} b_i = \sqrt{R^2 - [(\frac{m}{2} - i)d]^2}, \quad i = 1,2,\cdots,[\frac{m}{2}] \\ f_i = \frac{m}{2} - b_i \\ s_{i1} = f_i - \alpha f_i \\ s_{i2} = \sqrt{[(1-\alpha) f_i]^2 + (b_i - k)^2 - 2(b_i - k)(1-\alpha) f_1 \cos\theta_1} \\ \theta_1 = \frac{\pi}{2} - \arccos(\frac{2(h-c)}{a-2k}) \\ s_{i2} - s_{i1} < \alpha f_i \end{cases}$$

5. solving the nonlinear programming model

Based on the above nonlinear programming model, we can obtain the specific information at any situation given the height of any folding table and the diameter of the circular table to make the stability of the table best and the material less. For this situation where the height of the table is 70cm and the diameter of the table is 80cm, we use MATLAB to solve the nonlinear programming model and get the parameter $\alpha = 0.486$. The other parameters are shown as follows:

Table.1 The summary of size

a	*b*	c	*d*	*m*	*k*
158.00cm	79.90cm	3.00cm	4.70cm	34	39.60cm

Table.2 The slot length of each legs

The number of table leg	1	2	3	4	5	6	7	8	9
s_n (cm)	0	11.86	18.94	24.54	28.98	32.42	34.93	36.58	37.40

6. Conclusion

The Rising Side Table is the competitive products in industrial design. We take the optimal design dimension of the Rising Side Table as an example. Taking processing convenience as objective function and the geometric relationship between the table legs and the desktop as the constraint condition, we establish the nonlinear programming model and obtain the optimal design scheme. In the situation where the height of the table is 70cm and the diameter of the table is 80cm, we get the specific parameters as follow: the length of the table is 158cm, the width is 79.9cm, the thickness is 3cm, the width of the table leg is 4.70cm, and the number of the table legs is 34. The results show that the nonlinear programming method is a powerful tool in product design to look for optimal design scheme, which can save materials and the manufacturing cost of the mold, shorten the product development cycle.

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