The Study of Reducer Modeling Language Design Based on Symmetry

Xiaoli Fu*, Ting Li and Shufeng Yang
Zhongyuan University of Technology, Zhengzhou 450007, China

*fxlzzti@163.com

Abstract. Symmetry design is a kind of common design method in mechanical product design. The rational use of symmetry is helpful to realize the function of the product better, embody the symmetry of shape and meet the design requirements. This paper systematically analyzed the concept and type of symmetry, and established the symmetry system of reducer. From the perspective of material function and art form, the paper decomposed the structure of reducer and expatiated the relationship between global symmetric, component symmetry, and symmetry base elements. This paper by analyzing the symmetry of foreign brand reducer, present the whole shape determination of reducer box and the expression of symmetrical datum. Furthermore, it is used in the modeling language design of reducer, which is beneficial to highlight brand characteristics, optimize the modeling of reducer and upgrade the level of reducer design.

1. Introduction
Symmetry is widely used in mechanical product design. The earliest study of mechanical symmetry was Barrenscheen, a German scholar, that carried out a preliminary exposition of the conceptual system of mechanical symmetry[1]. The team led by Professor Feng Peien from Zhejiang University proposed the symmetry ontology of natural science to engineering science, they clarified the function, principle and time of the symmetry in the symmetry system[2]. Qi Yuxuan and others put forward the concept system of mechanical structure symmetry, and constructed the knowledge and design platform of mechanical product symmetry design[3]. Zhong Kangmin pointed out the basic idea of guiding the innovation of mechanical design with the idea of symmetrical aesthetics[4]. From the viewpoint of aesthetics and mechanics, Qiao Jizhong analyzed the application of symmetry in industrial modeling design[5]. And in the field of the design of the industrial general reducer (hereinafter referred to as "reducer"), Fu Xiaoli and her group studied the modeling of industrial general reducer from the aspects of brand culture and concept characteristics[6]. However, there is no research on modeling language design for product symmetry in previous studies.

In the form design of mechanical products, the form and language of the mechanical product should be given in the form of "deliberate" expression , following the principle of "shape and random energy", which reflects the applicability of the function, the symmetry and beauty of the shape[7]. So symmetry plays an important role in the design of reducer. On the basis of the symmetry analysis of the brand reducer, the symmetry theory and the expression method are put forward to guide the scientific application of symmetry in the design of the reducer's modeling language, which is to improve the design level of the reducer and the general product.
2. The type of symmetry
Symmetry is based on point C/ axis L\textsuperscript{n} or surface P. The up and down, the left and right, the ring and the oblique side appear in the form of same and repeated symmetry elements, and the symmetric sum of the set of symmetric elements is also called the symmetric space group. The symmetric space group consists of two parts, one is rotation and the other is the translation group of translational axisymmetric elements.

According to the symmetry benchmark requirements, symmetry graphs are represented by two dimensional and three dimensional views. Three kinds of symmetry are summarized below, as shown in Table.1:

- The mirror symmetry is also called the symmetric mirror Mi. Suppose an axis L\textsuperscript{n} or plane P, the same part of the graph is repeated by means of the reflection operation of this line or plane.
- Rotational symmetry L\textsuperscript{n}. Suppose that the number of times that a L\textsuperscript{n} axis is rotated for one week is n, and the minimum angle of rotation is α. The relationship between them is α = 360°/n.
- Translation symmetry Tr. When a symmetry element moves along a certain direction, it will coincide with its symmetrical elements.

| Space Expression | Mirror symmetry | Rotational symmetry | Translational symmetry |
|------------------|-----------------|---------------------|------------------------|
| 2-dimension      | ![Image]        | ![Image]            |                        |
| 3-dimension      | ![Image]        | ![Image]            |                        |

3. The Type of reducer
The reducer is widely used in different equipments. It can be divided into four main parts according to the input and output mode:

- The input and output mode is coaxial R series helical gear Hardened reducer.
- S series helical gear worm gear reducer with input and output mode as direct axis.
- K series spiral bevel gear reducer with input and output mode is direct axis.
- F series parallel shaft helical gear reducer with parallel input and output mode.

4. The symmetry system of the reducer
The reducer is an independent closed driving device between the prime mover and the working machine. It is the high-speed running dynamic generated by the motor or the inter combustion engine, which is through the gear transmission of the input shaft, the layshaft and the output shaft that achieve the purpose of deceleration[8]. The structure diagram of the R series reducer is shown below: schematic diagram is shown in Figure.1.

The reducer mainly composes of transmission parts (gears, shafts, etc.) and supporting parts (boxes, cover plates, flanges, etc.). Its symmetry mainly composes of material function and artistic form. It includes three design elements, which refer to the whole box, structural parts (the box position of M1-M6, schematic diagram is shown in Figure.2), and symmetrical benchmark (the repeatability of symmetry elements).
4.1. Symmetry of material function
On the premise of the function structure of the reducer meeting the requirements of symmetry of material function, taking the R series helical gear reducer as an example, the material function symmetry Sf was divided into functional holistic symmetry Sw, functional component symmetry Sp, functional symmetric reference element Sbe, and the material function symmetry Sf = (Sw, Sp, Sbe) of the reduce, schematic diagram is shown in Figure.3:

- Functional holistic symmetry Sw = (Sem≤ Sre). The weight relationship between reducer Sre and motor Sem is symmetrical.
- Functional component symmetry Sp = (Str, Sbr, Sdis). The transmission part Str is composed of gear, input shaft, intermediate shaft and output shaft, and the support part Sbr is composed of box, flange, ground board, hanger and cover plate; and the radiator Sdis is composed of heat dissipation lines on one side or two sides of the box to complete the symmetry of function.
- The function symmetry benchmark element Sbe = (Sde, Sdes, Sstr). Functional requirements Sde, function design Sdes and function structure Sstr are symmetrical.

The main material function symmetry is functional global symmetry Sw = (Sem = Sre), transmission equilibrium symmetry Str and equilibrium heat sink Sdis.

4.2. Symmetry of art form
Under the premise of satisfying the symmetry of art form, the art form symmetry of reducer Sa was divided into the overall symmetry of box form Sab, the form symmetry of component Constituent Sap and the form symmetry of base element Sabe, so the art form symmetry of reducer Sa = (Sab, Sap, Sabe), schematic diagram is shown in Figure.4:
• The overall form symmetry of box Sab. It is composed of the symmetry of the overall M₆ shape of the reducer box Sdc and the symmetry of the shape details Sda. Among them, the form symmetry of the reducer box M₆ Sdc is determined by the symmetry square of 4 axis. And the symmetry of line segment a, a', h, h' evolves into the symmetric form of 1 axis, 2 axis and 6 axis. After the initial shape is determined, the symmetry of the shape details Sda adjust the symmetry in detail through the surface Pa, Pa', Ph, Ph', final shape is obtained. Refer to the overall shape determination of the box and the symmetry of detail adjustment expression method, schematic diagram is shown in Figure.5.

• The form symmetry of component Constituent Sap = (Spar, Sdh). The support Spar is composed of a box, a flange, a floor board, a hanging ear, and a cover plate. The heat dissipation component, Sdh, is composed of the heat dissipation lines on one side or both sides of the box to complete the symmetry of the shape.

• Form symmetry base element Sabe. The symmetrical base element is based on the symmetrical point C/ axis L₀/ surface P/ angle alpha as the symmetry reference. The form of the reducer is expressed by symmetrically, and the symmetry datum expression method is referenced, as shown in Table.2. To checks the form symmetry of reducer for correctness, refer the symmetry theorem to judge as follows[9]:
  - Definition 1: if there is a secondary axis L₂ perpendicular to the n subaxis L^n, then there are nL^n vertical n times L^n——L^nL^n;
  - Definition 2: if there is a symmetric surface P Contained the n subaxis L^n, then there are n P Contained n times L^n——L^nL^n;
  - Definition 3: if there is an even time axis vertical symmetry plane P, then a symmetric center C must be generated at the intersection point between the symmetry axis and the symmetric plane——L^nPC.

The main artistic form symmetry Sa has the form symmetry Sdc, flange form symmetry Spar and heat sink shape symmetry Sdh.

Figure 4. The symmetry system of the art form of the reducer.

Figure 5. The overall shape determination of reducer box and the symmetry adjustment expression method of detail.
Table 2. Symmetric benchmark expression method.

| Axis of symmetry L^n | 1 | 2 | 4 | 6 |
|----------------------|---|---|---|---|
| Center of symmetry C | 0 | 1 | 1 | 1 |
| Symmetry plane P     | 1 | 2 | 4 | 6 |
| Base angle α         | 360°| 180°| 90°| 60°|
| Morphological symmetry | L \(^1\) | L \(^2\) | L \(^4\) | L \(^5\) |

5. The analysis of the symmetry modeling language for the brand reducer

In the aspects of the reducer's form and design, the design principle of "shape random energy" must be followed by us, which can reflect the practicability of function and it should emphasize on "form follows emotion", which means that express the emotion expressed by the reducer through morphological language. Because most of the domestic reducer products imitate the foreign brand reducer, we select the three main functions and forms of the four major series of reducer, BAUER, SEW and BONFIGLIOLI, to carry out symmetry extraction, and carry out the symmetrical elements analysis of the selected reducer through the material function, the symmetry system of art form and the symmetry datum expression method, as shown in Table 3. The modeling language is summarized and the symmetry rules of the reducer series and the brand are explored.

Under the established condition that the main material function symmetry of the reducer is balanced, the modeling language of the symmetry for the art form can be divided into two parts. The first part is the main body modeling language \(M_{\text{m}}\), which mainly refers to the overall symmetry modeling language of the reducer box; the second part is the auxiliary body modeling language \(M_{\text{a}}\), mainly includes the flange and the heat dissipation symmetry modeling language, as shown in Table 4.

Table 3. Symmetry element analysis of brand reducer (a).

| Series | BAUER |
|--------|-------|
| Product form | Function Sf | Form Sa |
| Sw | Weight balance | R | — | — | — |
| — | Balance of transmission force | — | — | Curve | Octagon |
| — | Heat dissipation balance | — | — | — | — |
| — | Heat dissipating pattern of box | — | — | — | — |
| Str | — | — | — | — | — |
| Sw | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| S | Weight balance | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| K | Weight balance | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| F | Weight balance | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |
| — | — | — | — | — | — |

5
Table 3. Symmetry element analysis of brand reducer (b).

| Series | Product form | Function Sf | Form Sa |
|--------|--------------|-------------|---------|
|        | SEW          |             |         |
| R      | Sw           | Str         | Sdis Mi | L^n Tr |
|        | Weight balance | Balance of transmission force | Heat dissipation balance | Box Flange Heat dissipation |
| R      | —            | —           | —       | Octagon linear |
| S      | Weight balance | Balance of transmission force | Heat dissipation balance | Box Flange Heat dissipation |
| S      | —            | —           | —       | Round Linear |
| K      | Weight balance | Balance of transmission force | Heat dissipation balance | — Flange Heat dissipation |
| K      | —            | —           | —       | Round Linear |
| F      | Weight balance | Balance of transmission force | Heat dissipation balance | Box Flange Heat dissipation |
| F      | —            | —           | —       | Round Linear |

Table 3. Symmetry element analysis of brand reducer (c).

| Series | Product form | Function Sf | Form Sa |
|--------|--------------|-------------|---------|
|        | BONFIGLIOLI  |             |         |
|        | SEW          |             |         |
| R      | Sw           | Str         | Sdis Mi | L^n Tr |
| R      | Weight balance | Balance of transmission force | Heat dissipation balance | Box Flange Heat dissipation |
| R      | —            | —           | —       | Round Linear |
| S      | Weight balance | Balance of transmission force | Heat dissipation balance | Box Flange Heat dissipation |
| S      | —            | —           | —       | Linear |
| K      | Weight balance | Balance of transmission force | Heat dissipation balance | Box Flange Heat dissipation |
| K      | —            | —           | —       | Round Linear |
| F      | Weight balance | Balance of transmission force | Heat dissipation balance | Box Flange Heat dissipation |
| F      | —            | —           | —       | Round Linear |
Table 4. Modeling language analysis of the symmetrical law of brand reducer.

| Series | BAUER | SEW | BONFIGLIOLI | BAUER | SEW | BONFIGLIOLI |
|--------|-------|-----|-------------|-------|-----|-------------|
| R      | Box   | Flange | Heat dissipation | Box   | Flange | Heat dissipation | Box   | Flange | Heat dissipation |
|        | Bi-axial | Octagon | Cube | Bi-axial | Octagon | Linear | Uniaxial cube | Round | Curve |
|        | Symmetrically | Fluency | Rule | Symmetrically | Precise | Light | Full | Fluency |
| L^2PC  | L^2PC | L^1P | Stability | Full | Stability | Full | Order | Stable | Rigorous |
|        | Bi-axial | Octagon | Curve | Bi-axial | Octagon | Linear | Biaxial cube | Octagon | Linear |
| S      | Rule | Symmetrically | Fluency | Rule | Symmetrically | Precise | Rule | Symmetrically | Precise |
| L^2PC  | L^2PC | L^2PC | Stability | Full | Stability | Irregular body | Round | Linear | Biaxial cube | Round | Linear |
|        | Round | Round | Curve | Full | Bias | Full | Precise | Rule | Full | Precise |
| K      | Uniaxial cube | Rigorous | Variable | Rigorous | Order | Stability | Full | Order | Rigorous |
| L^1P   | L^2PC | L^1P | Round | Curve | Uniaxial cube | Full | Precise | Rule | Full | Precise |
| F      | Light | Stable | Rigorous | Light | Stable | Rigorous | Order | Stability | Rigorous |

5.1. Analysis of subject symmetry modeling language

The whole box of brand BAUER, SEW R, S series, BONFIGLIOLI S, K, F series reducer is dual axis symmetrical body, box M_8 has L^2 sub symmetric axis, 2 symmetric plane P, a symmetric center point C, symmetrical rule combination for L^2PC can be upward / down / left / right mirror, rotating symmetry; The main body of the speed machine is a single axis symmetrical body, and the box M_6 has L^1 sub symmetric axis, 1 symmetric surface P, no symmetric center point C, and the symmetry rule is composed of L^1P to the left and right mirrors, while the K series of the brand SEW is irregular and the box M_6 has no symmetrical C/ axis L^1/ P.It is concluded that the subject symmetry law of the reducer box subject of the brand BAUER reducer is 2 times L^2PC=2 times L^1P, and the subject symmetry law of the reducer box subject of the brand SEW is composed of 2 times L^2PC>1 times L^1P, and the subject symmetry law of the reducer box subject of the brand BONFIGLIOLI is composed of 3 times L^2PC>1 times L^1P.

It is concluded that the symmetry law of the M_8 body modeling language of the deceleration chassis is L^2PC>L^1P, and the form is 2 axisymmetric L^2PC, followed by the uniaxial symmetry L^1P. The 2 axisymmetric shape is regular and stable, while the uniaxial symmetry shape modeling language not only shows symmetry and stability, but also presents a lightweight and flexible visual effect.

5.2. Analysis of auxiliary symmetry modeling language

In the R, S, F series of the brand BAUER, the flange of the R series of SEW and the S series of BONFIGLIOLI is the rotation symmetry of the multi symmetry axis L^8, showing the positive eight sides, and the symmetry rule combination is L^8PC;the K series of brand BAUER, SEW's S, K, F series and BONFIGLIOLI's R, K and F series are flanged symmetrical circular flanges, and the
symmetry rule combination is \( L^1P \). It is found that the shape of flanges is mostly circular rotationally symmetric \( L^1P \), while the shape of some flanges is \( L^8 \) with a symmetrical eight axis \( L^8P \). Most of the flanges of the four Chinese-brand reducers are also circular symmetrical \( L^1P \). Therefore, the external shape of the flange is a design principle that follows the function of the internal structure, which conforms to the functional requirements, functional structure and function design of the torsion and transmission of the bearing, and determines the form of the speed reducer. The form of symmetrical pattern of flanges is \( L^1P > L^8PC \). The shape of the flange is symmetric and round, followed by regular octagon of axis, the shape of regular octagon is close to round, and the circular shape language is plumpness and rigorous, and the eight sides are plumpness and symmetry.

There are two forms of heat dissipation symmetry in the four series of reducer of brand BAUER, SEW and BONFIGLIOLI: one is the side of the BAUER heat dissipation line with a curve in the upper and lower unit mirror symmetry, while the SEW and BONFIGLIOLI heat dissipation lines are symmetrical in line. The other because of BAUER, SEW, BONFIGLIOLI deceleration chassis most is 2 axisymmetric bodies, the symmetry rule is \( L^2PC \), and the heat dissipation lines are distributed on the symmetric surface \( M_2, M_4 \), and then the other side heat dissipation lines are shot through the center symmetric axis mirror of the box. From the above analysis, the most symmetrical form used in the design language design is the straight line, followed by the curve. The modeling language of the straight line is accurate and order, but the curve is rich and fluent.

To sum up, the design of the brand reducer should reflect the "stability" from the perspective of the language of the main subject modeling or the auxiliary modeling language. And the expression language is conveyed in a stable, accurate and all term.

6. The example of the reducer symmetry modelling language design

Based on the above knowledge, in the case of the symmetry of the material function, taking the R series reducer as an example, the knowledge of symmetry rules is applied to design a stable and symmetrical reducer with a precise and symmetrical shape. And its form drawing will be given.

6.1. The design of the symmetry modeling language for the whole shape of the box

In order to meet the factors such as the overall material function and the stability of the art form of the reducer box, the frequency of the symmetry axis \( n \) must be set to \( n < 5 \) and cannot be equal to 3, so that the whole shape of the box is more stable. The whole shape of the reducer is designed as a single axisymmetric square \( L^1P \) by means of the Sdc method for determining the symmetry of the whole \( M_6 \) shape of the box body. Design of morphological details using symmetric Sda method. Some symmetrical detail adjustments are made by the line segment a, e mirror symmetric out of a ‘h, Pa (P1~P4) mirror (P1~P4) mirror and Pa’ (P1’~P4’), and the final shape is determined, schematic diagram is shown in Figure.6. The design language of the reducer embodies the stability that must be embodied in the function form, and after the adjustments of the symmetry of the shape details, the modeling language is lighter and more flexible.

6.2. Design of flange shape symmetry modeling language

The shape of flange must conform to the demands of the functional connection of bearing torsion and transfer force. Its function determines that most of the flanges should be set to round and rotated symmetry, distributed on the surface \( Pb, Pc, Pd, Pf, Pb', Pc', Pd', Pf' \). The modeling language used for the reducer flange is called strong hexagon, and the symmetry combination rule is \( L^6PC \), schematic diagram is shown in Figure.7.

6.3. Shape symmetry modeling language design of heat dissipating pattern

The design of heat dissipating pattern is a symmetrical hexagonal arrangement with good symmetry and stability, schematic diagram is shown in Figure.8. The combination of symmetry rules is \( L^6PC \), which is divided into translation and mirror symmetry. The heat dissipation lines are distributed on the \( M_2 \) and \( M_4 \) surfaces of the box uniformly, and play the role of balanced heat dissipation. In the form
presentation, the curve is arranged with the regular hexagon, and the curve in the stable box can make the modeling language more varied and fluent.

Figure 6. Overall shape of reducer box. 

Figure 7. Flange shape of reducer.

Figure 8. Heat dissipation pattern of reducer.

7. conclusion
Symmetry is ubiquitous in the field of mechanical product design and contributes to meeting the requirements of mechanical products. Not only in the field of the function of the reducer, but also in the field of the art form, the mechanical is reflected the symmetry. In order to meet the demands of reducer design, the symmetry system of reducer should be set up, and the relationship between components symmetry and symmetry datum elements should be clarified. Based on the analysis of the symmetry of the foreign brand reducer, the symmetry law and symmetry method of the reducer's form datum are put forward. It is used in the design of the reducer's modeling language to highlight the brand characteristics, optimize the modeling of the reducer and improve the design level of the reducer and its similar products.

References:
[1] J Barrenscheen 1990 Die Systematische Ausnutzung von Symmetrieeigenschaften beim Konstruieren (Technische Universität Braunschweig Fakultät für Maschinenbau und Elektrotechnik)
[2] Feng Peien, Ma Zhiyong, Qiu Qing Ying, Shen Menghong and Ceng Lingbin 2008 Research on symmetry ontology from natural science to engineering science (natural science exhibition) p 1441-1450
[3] Qi Yuxuan, Qiu Qing Ying, Feng Peien and Li Lixin 2016 Conceptual structure and application of combined symmetry of mechanical structure (Zhejiang:Journal of Zhejiang University Engineering Edition) p 1889-1901
[4] Zhong Kangmin and Wang Mingdi 2004 Symmetry beauty and mechanical design innovation (Suzhou:Journal of Soochow University Engineering Edition) p 36-37
[5] Qiao Jizhong 1988 Application of symmetry in industrial design (Xi'an:Journal of Xi'an Technological University) p 64-68
[6] Fu Xiaoli, sun Xu Fang and Chen Fang 2014 Research on Modeling Design of industrial general reducer (Tianjin:mechanical design) p 108-110
[7] Zuo Tiefeng, Shu Wei, Zhang Shuai and Geng Dian Mei 2015 product form language and design (Shenyang: Liaoning Art Publishing House) p 12-13
[8] Yang Zhi and Chen Xuedong 1991 Vibration analysis of the axisymmetric reducer's shaft system (Wuhan: Wuhan Polytechnic University) p 84-89.
[9] Shi Nicheng and Li Guowu 2008 Symmetry and crystallography (Shanghai:natural journal) p 44-49