Ming-style chair parts and its group technology application research

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Abstract. In order to apply the group technology to the production of Ming style furniture, enhance the ability of enterprises to cope with the production of small-batch, multi-variety furniture, this article will take Ming-style chair furniture as an example to make a reasonable division of its parts. The types of Ming-style chair parts are combed, the characteristic information of each component is extracted and the joint mode of mortise and tenon between two parts is summarized. In this way, the process of each mortise and tenon structure is summarized, and the correspondence between mortise and tenon structure and the machinery is established. According to this method, the Ming-style chair parts are summarized and classified into 211 kinds. Based on the similarity of parts processing machinery, all parts of the Ming-style chairs are classified into groups by fuzzy clustering algorithm and MATLAB software calculation. The purpose of this article is to provide a divisional idea for the pre-part classification preparation of Ming-style chair parts in groups for the part family.

1. Introduction

Ming-style chairs have the characteristics of complex structure and a wide variety of parts, and their parts are divided into multiple categories due to their different material types and joining methods. In the production and manufacturing, the processing process becomes complex due to the differences of material types of various parts and mortise and tenon. In order to improve the production efficiency of Ming-style chairs, group technology is introduced into it. Group technology classifies parts into families according to the similarity between parts and certain standards, and carries out the classified layout of processing machine tools on this basis, so as to realize the large-scale production of multi variety and small batch parts [1]. Li G P proposed that the group technology is suitable for domestic furniture production in the article "The Application of Group Technology in Furniture Production" [2]; With the cross and integration of disciplines, there are more possibilities for research methods, Hao J X[3] and Jia Y[4] introduced mathematical algorithms into the group technology, and performed group analysis on panel wardrobes and custom kitchen cabinets through fuzzy clustering algorithms; Han W S[5] analyzed the grouping method of panel furniture and put forward his own opinions on the grouping of drilling process in the processing process; Xu JH[6] used the time research method to study simple solid wood chairs and its parts, and applied group technology to guide the production, so that the optimized solid wood chairs can save production costs and improve production efficiency. Different from the above-mentioned research objects, Ming-style chair parts are diverse in types and the processing technology of joint tenon and tenon joints is complicated. Clearly categorizing its parts and clearly
corresponding to the processing machine tool can lay a good foundation for the subsequent application of fuzzy clustering algorithm for effective grouping.

2. Feature division of Ming-style chair parts
Ming-style chairs can be divided into backrest chairs, armchairs, armchairs and top chairs according to their shapes [7]. Its basic structural parts include chair legs, backrests, headrests, armrests, seat surfaces and other components; The rest of the parts are Lianbang stick, short old, clip flower, coupon mouth tooth, horn tooth, tooth strip, etc., most of which play a decorative role. In addition to the mortise joints that are combined with other structural components, the basic structural components also need to consider the mortises, mortise grooves, round holes, etc. that need to be opened when joining with other parts.

2.1 The feature division of chair legs
The legs of Ming style seats are made of a wooden link, which is generally designed to be below the upper circle, and then the lower part is processed into the inner side of the outer circle. Because the cross section of the lower square material is larger than that of the upper round material, it supports the seat surface [1]. Taking into account that the straight and profiled legs are different in the initial cutting and rough planing stages, the two are distinguished in the division of parts. For round material chair legs, the square material must be milled into round material by a vertical milling machine with a fillet cutter in the initial stage of the net material processing. Therefore, the straight material and profiled material chair legs are further divided into pure square material and chair legs with round wood. Considering that the joints of the front legs of the subsequent chair will be different due to the difference between the back chair and the armchair, the back chair and the armchair are also divided, as shown in Figure 1 for the feature division of the chair legs.

![Fig.1 Classification of chair legs](image)

2.2 The feature division of handrails and brains
For more special armchairs, the armrests are generally called "crescent armrests". The difference with backrest chairs and armchairs is that the backrest and armrests are in the form of a seat ring. The entire chair ring is made of three or five arc sections by Wedge nail tenon [8], so the armrests of the chair are listed as a single category in the profile. The division of the rest of the armrest and the brain is the same as the division of the chair legs above, the division is shown in Figure 2 and 3.

![Fig.2 Classification of handrails](image)
2.3 Characteristic division of backrest and seating surface

The seat back is divided into whole board, jigsaw and comb back [1]. Except for the horizontal back frame in the jigsaw backrest, the vertical and back sheets of the rest back frame are divided into straight and profiled materials. The uprights of the backrest frame are divided into square and round materials. Plates are divided into plain panels and carved panels on the basis of the material type distinction. In addition to the distinction between straight and profiled materials, the comb back is further divided into round and square materials. The specific division of the backrest is shown in Figure 4. The seat surface is composed of a side wiper, a seat panel and a wear belt. The seat panel can be divided into independent board and jigsaw board. Side wipe and threading are both square and straight materials and do not need to be divided in the cutting stage.

2.4 Feature division of other parts

Other parts of Ming style seat include Cheng class, union stick and teeth. Cheng class can be divided into Zhicheng, Luoguocheng and pin completion. As the name suggests, Zhicheng is straight material, it can be divided into square straight wood and round straight wood; Luoguocheng is a profile, which is divided into square profile and round profile; The tube foot cheng is a square and straight material that supports the leg. Lianbang sticks are generally shaped round materials with a thin upper part and a thick lower part [8], but it is also used as a square material for chairs that are rarer in the shape of a square material. The teeth, including the bill mouth teeth, the teeth bars and the horn teeth, they are all irregular shaped materials. The short and old are straight wood, which can be divided into round wood and square wood.

3. Division of mortise and tenon between various parts of Ming-style chairs

3.1 The mortise and tenon between the legs of the chair and the parts

The front and rear legs of the armchair are made of one piece of wood, and the chair legs are connected to the armrest or the brain after passing through the seat surface. Whether the chair leg itself is made of square or round wood and the lap head or armrest connected with it comes out or not corresponds to different tenons and mortises [9]. The connection between Ming-style chair leg parts and the brain or armrest can be divided into square material T-joint, square material corner joint, round material T-joint and round material corner joint. The T-joint means that the armrest or lap head comes out when it is connected with the chair leg, and the corner joint means that the lap head and the armrest do not come out when they are connected with the chair leg. Generally, straight tenon or lattice shoulder tenon is adopted for the T-joint of chair legs and armrests or brain square materials; Chucking tenon shall be used for corner joint of square materials; Round timber T-joint is connected through floating shoulder
tenon; Round timber corners shall be connected through cigarette bag digging pot (straight joint) or collet dovetail tenon (joint is 45°inclined shoulder) [7].

In addition to the mortise and tenon joints of the legs and structural parts, whether they are jointed with other parts should also be considered. When the legs are connected with the Cheng, if the Cheng are round, the two are connected by a floating shoulder tenon; When the Cheng is square timber, it is connected by straight tenon or grid shoulder tenon; In addition to the above-mentioned two joining situations of the square material, the tube foot cheng can also be connected with the leg of the round material through a floating shoulder tenon. If the leg has corner teeth or coupon openings, just open a tongue and groove on the leg to insert the corner teeth and coupon openings.

![Diagram](image)

**Fig.5 The mortise and tenon division required for the joint between the legs of the chair and the parts**

### 3.2 The mortise and tenon between handrail and parts

The parts joined with the armrests are the front and rear legs of the chair and the Lianbang sticks. The situation of mortise and tenon when the chair legs are joined to the armrests has been analyzed above. If there is a Lianbang stick combined with the armrest, open a round hole on the armrest and insert the Lianbang stick. The armrest of the armchair is the front part of the chair circle, and the back part of the chair circle is connected by a Wedge nail tenon [10]. The armrest of the ring chair itself is round material, and most of it comes out when it is connected with the front leg, with straight tenon; If the armrest does not come out, a single silver ingot tenon (45°oblique shoulder) or straight tenon (straight seam) can be produced.

### 3.3 The mortise and tenon between the brain and the parts

The parts connected with the lap head include the back legs of the chair, the back plate or mullion backrest and the corner teeth. The mortise and tenon used for the joint with the rear leg of the chair have been combed above. When the lap head is connected with the back plate and corner teeth, it needs to be tenoned; If the mullion is round, a round hole shall be opened, and a straight tenon shall be opened for square material. For the more special armchair, in this paper, the armchair and back chair are classified as the lap of armchair and back chair. In addition to being tenoned with the front seat ring through wedge nails, the middle and rear section of the seat ring also needs to be connected with the chair leg through floating shoulder tenon. If the corner teeth are connected to the seat ring, the seat ring can be mortised or straight mortise.

### 3.4 The mortise and tenon between backrest and seat surface

The backrest of the whole board is directly connected with the head and the edge of the seat surface, without processing the tenon [8]; The plate milling tenon in the panel backrest is embedded in the tenon groove of the backrest frame. The outer frames of the panel backrest are connected through the grid shoulder tenon, with the seat surface through the straight tenon, and with the lap joint through the straight tenon, grid shoulder tenon or floating shoulder tenon. The round wood comb back can be directly inserted into the round hole opened by the lap head, and is connected with the seat surface through a
straight tenon; The square material comb back is tenoned at both ends and connected with the seat surface and lap head.

The large side of the seat surface and the wiping head are connected by a grid corner tenon [11], and a round hole is opened in the middle to allow the chair legs to pass through. The eyes are joined to the front and back legs, belts, backrests, Lianbang sticks, short old or clip flowers. Seat panels are divided into individual panels and panels, both of which need to be slotted and tongued, and the connection between the panel and the panel mainly adopts the dragon and phoenix tenon [8]. In addition to connecting the straight tenon with the side wiper, the threading is also connected to the threading groove of the panel through the tongue.

3.5 The mortise and tenon of other parts
The main joint parts of the complete type are the chair legs. The complete type of round timber can be connected with the chair legs through floating shoulder tenon, and the square timber can be connected through straight tenon or grid shoulder tenon. While the straight and Luoguocheng in the complete class are connected with the chair legs, they may also be connected with the low old and clip flowers through straight tenon or planting tenon. According to the above analysis of the joint between the chair leg and various parts, the pin is relatively special. In addition to the two kinds of mortise and tenon available for the above square materials, it can also be connected with the chair leg through floating shoulder mortise. When the upper bar is connected with the handrail, it does not need to be tenoned, but can be directly connected with the round hole opened by the handrail; It is connected with the seat surface through straight tenon. Teeth include mouth teeth, dental strips and angular teeth. The teeth of the coupon mouth are connected through the chucking tenon, and the teeth of the coupon mouth and the tooth strip can be directly embedded in the tenon groove opened by the edge plastering and the chair leg. The installation methods of corner teeth include direct installation, direct installation while planting tenon, and planting tenon while leaving straight tenon [6]. Short old and clip flowers play the same role in Ming style furniture, both of which are combined with the edge plastering of complete class and seat surface. The clip flower is connected with the complete type and edge plastering through a straight tenon or planting tenon; The low old and side plastering are connected through straight tenon. When they are connected with the complete type, the square material is provided with lattice shoulder tenon, and the round material is provided with floating shoulder tenon.

4. Analysis on processing technology of Ming style chair parts
The clustering algorithm used in this paper is based on the production process analysis method. This chapter analyzes the production process and processing machinery of Ming style chair furniture, so as to pave the way for the realization of subsequent group technology.

The production stage of Ming style chairs includes raw material processing stage and net material processing stage. In the processing stage of chair parts, the cross-section and longitudinal solution of straight wood can be completed by circular saw; The profile needs to be cut and scribed first, then sawed by the joinery band saw through the circular saw according to the drawn line [13]. In the raw material processing stage, regular square materials can be roughened directly by flat and press planers; The arc surface of profile needs to be trimmed by vertical milling machine equipped with trimming cutter. For plates that need to be spliced, they need to be spliced with the help of a splicing machine.

**Fig.6 Flow chart of mechanical use in straight and profiled material processing stage**
Net material processing includes milling square materials into round materials, tenon and mortise processing, opening round holes and other processes. The machine tools involved include vertical milling machine, five disc saw, square tenon machine, woodworking drilling machine, etc. Among them, the vertical milling machine involves many processing procedures, so it is subdivided according to different tools, including fillet cutter, slot cutter, pointed cutter, T-cutter and disc cutter. In the net material processing, mortise and tenon processing accounts for the main part. This paper involves the machine tools required for mortise and tenon processing, as shown in Figure 7. The machine tool selected for each processing procedure is the basic machine tool commonly used in most factories. It will be different in different factories, and each factory can adjust it according to the actual situation.

![Fig.7 Machine tools needed for tenon and tenon processing](image)

### 5. Case analysis of group technology implementation of Ming style chair parts

Group technology is to divide the parts with similar processing technology into a part family for production and processing. After the parts are grouped, it not only improves the production efficiency, but also makes the maximum use of the processing machine tools, and provides a certain basis for the arrangement of machine tools in the factory. In this paper, fuzzy clustering algorithm is used to analyze the realization of group technology of Ming style chair parts through MATLAB software. First construct the part-machine association matrix, r parts M (M1, M2, M3, M4...Mr) use j machine tools Y (Y1, Y2, Y3, Y4...Yj) in the machining process, and the matrix is

\[
A_{ij} = \begin{bmatrix}
a_{11} & a_{12} & \cdots & a_{1j} \\
a_{21} & a_{22} & \cdots & a_{2j} \\
\vdots & \vdots & \ddots & \vdots \\
a_{r1} & a_{r2} & \cdots & a_{rj}
\end{bmatrix}
\] (1)

A comprehensive analysis of the shape of the parts themselves and the mortise and tenon required for the joints in the previous section show that there are 211 types of Ming-style chair parts and 18 types of machine tools for processing chair parts. Based on this, the binary matrix of the part-machine tool is constructed, and each part is marked with "1" at the machine tool position that has been processed; the other machine tools that have not been processed are marked with "0". \(a_{it}\) is the relationship between any part \(M_i\) and any machine tool \(Y_t\) [5].

\[
a_{it} = \begin{cases} 
1 & \text{The part goes through this processing machine} \\
0 & \text{This part does not go through this processing machine}
\end{cases}
\] (2)

The establishment of the part-machine binary matrix table is shown in Table 1 below. Due to the excessive classification of parts, this article only lists the armrest part. In the table, P1 to P18 are respectively represented as circular sawing machine, joinery band sawing machine, flat planing machine, planer, trimming cutter milling machine, jigsaw machine, fillet cutter milling machine, slot cutter milling
machine, package tip cutter milling machine, T-type Knife milling machine, disc milling machine, five-disc saw, square tenon machine, woodworking drilling machine, hand gong machine, smooth planer, belt sander, engraving machine.

| Tab.1 Parts-machine tool binary matrix table |
|--------------------------------------------|
| Parts | Grouping | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | P11 | P12 | P13 | P14 | P15 | P16 | P17 |
|-------|----------|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K1    |          | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| K2    |          | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 |
| K3    | Round armrest direct mater | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| K4    |          | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 |
| K5    | L-type   | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| K6    |          | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| K7    |          | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| K8    |          | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| K9    |          | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| K10   |          | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| K11   |          | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| K12   | Round handrail profile | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| K13   |          | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| K14   |          | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 |
| K15   | Armrest  | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| K16   |          | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| K17   |          | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| K18   |          | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| K19   |          | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| K20   |          | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| K21   | Round handrail profile | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 |
| K22   |          | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 |
| K23   |          | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| K24   | Square armrest straight material | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| K25   |          | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| K26   |          | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| K27   | Square armrest profile | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| K28   |          | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |

Calculate the similarity between the two parts using processing machinery by the similarity coefficient method. The more the same number of machinery used in the processing of the two parts,
the greater the similarity between the two parts. The calculation formula for the similarity \( P_{mn} \) between the part \( M_m \) and the part \( M_n \) is shown in Equation 3 [14].

\[
P_{mn} = \frac{\sum_{k=1}^{j} a_{mk} \cap a_{nk}}{\sum_{k=1}^{j} a_{mk} \cup a_{nk}} \tag{3}
\]

The similarity matrix \( P_{ij} \) of the parts is constructed from the similarity between the parts, as shown in equation 4. Calculate this matrix by the transitive closure method until \( P^n = P^n \) to obtain the equivalent matrix \( P^n \).

\[
P_\eta = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1r} \\ p_{21} & p_{22} & \cdots & p_{2r} \\ \vdots & \vdots & \ddots & \vdots \\ p_{r1} & p_{r2} & \cdots & p_{rr} \end{bmatrix} \quad p_{\eta} = p_{\eta} p_{\eta} \in [0, 1] \tag{4}
\]

For the calculation example of the transitive closure method, as shown in Equation 5.

\[
R \cdot R = \begin{bmatrix} r_{11} & r_{12} \\ \vdots & \vdots \\ r_{21} & r_{22} \end{bmatrix} \cdot \begin{bmatrix} r_{11} & r_{12} \\ \vdots & \vdots \\ r_{21} & r_{22} \end{bmatrix} = \begin{bmatrix} \text{Max}[\min(r_{11}, r_{11}), \min(r_{12}, r_{11})] \\ \text{Max}[\min(r_{21}, r_{11}), \min(r_{22}, r_{11})] \\ \text{Max}[\min(r_{11}, r_{21}), \min(r_{12}, r_{22})] \\ \text{Max}[\min(r_{21}, r_{21}), \min(r_{22}, r_{22})] \end{bmatrix} \tag{5}
\]

The elements included in the equivalent matrix \( P_\eta \) calculated by MATLAB software are 0.750, 0.778, 0.800, 0.833, 0.857, 0.875, 0.889, 0.900, 0.909, 0.917, 1. Take one of the above elements as the threshold \( \lambda \) to construct the intercept matrix \( P_\lambda \). The similarity coefficients in the equivalent matrix that are smaller than the threshold \( \lambda \) are taken as 0 at the corresponding position of the cut matrix \( P_\lambda \), and otherwise taken as 1[3]. In the cut-off matrix, the parts with the same row in the same row are a part family. The grouping of different thresholds is shown in the following table after MATLAB calculation.

| Threshold  | 0.750 | 0.778 | 0.800 | 0.833 | 0.857 | 0.875 | 0.889 | 0.900 | 0.909 | 0.917 | 1.000 |
|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Number of groups | 1 | 6 | 6 | 7 | 16 | 26 | 59 | 59 | 77 | 92 | 92 |

Due to the differences in the number of operating workers, floor space, and the type and number of machine tools used in each factory, the selection of thresholds for each factory can be flexibly adjusted according to its actual situation, so as to achieve reasonable, efficient and professional production. For example, a factory with a small production area can choose to divide the parts into groups 6 or 7, a medium-sized factory can choose to divide into groups 16 or 26, and a large factory with a large number of workers and a large area can choose to divide the parts into 59 or 77 groups.

6. Conclusion

According to the different processing technology, the parts themselves are divided into straight round, straight square, special-shaped round, and special-shaped square. According to the different types of materials and the joints between parts, the situation of the joints required for joints is summarized. Use fuzzy clustering algorithm to group Ming-style chair parts that have been analyzed in the production process and form a binary matrix with the machine tool through MATLAB software. After grouping, it is concluded that small factories can divide Ming-style chair parts into 6 or 7 groups for production, the medium-sized factories can divide into groups 16 or 26, and the large-scale factories can divide into groups 59 or 77. In this paper, the introduction of group technology into production can effectively improve production efficiency, reduce unnecessary transportation of parts between machine tools, and rationally arrange the layout of machine tools, providing a reference for Ming-style chair enterprises to introduce group technology into production.
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