**JYPB2.0—A new composition adjustment processing system of metal melting**

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**Abstract:** The new system contains all the independent variables, setting the ultimate objective function groups, installing the complete operating program chain and establishing the accurate mathematical model. The new system produces the ultimate objective function group—Optimum Proportion Scheme through the processing of the eleven operating main programs such as Optimization Program, etc. and revising of three operating auxiliary programs such as Elimination Program, etc. which is locked by the intermediary objective function group. The setting of the complete database system provides the full-service for the customers’ smelting production. It is generally applicable for all the varieties of alloys and raw materials. Its customized features can fulfill the actual needs of users. These are the advantages of the new composition adjustment processing system of metal melting—JYPB2.0.

**Key words:** objective function group; optimum proportion scheme; operating program chain

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**M**etallic materials (ferrous metal and non-ferrous metal) are very important in industrial production; all the metallic materials have to meet the strict composition requirements. The composition adjustment has to be done through the melting process to acquire the pre-determined composition of the metallic materials, and the basis of the composition adjustment operation is processed through composition adjustment calculation—burden calculation and additive amount calculation.

There are two shortcomings in the existing calculation technique and one impediment in the existing software. The shortcomings are:

1. Inaccuracy of calculation results, deviation of the adjusted composition.
2. The calculations are not integrated with the cost effectiveness analysis.

The impediment is: the software limits the varieties of steel and the raw materials, and it is not possible for the users to develop new steels and the use of the new materials.

The new system makes up for the shortcomings, and removes the impediment in the existing software. It significantly improved the composition adjustment calculation and extends the field of application.

**1 Principle of the software programming**

The software incarnates our management concept: customer first and serve with advanced technology.

1.1 Advanced technology

It represents the principle of the integration of technology and economy, and also to compromise the composition and cost to meet the following three requirements:

a. Realizing the exactitude of composition: the deviation between the adjusted composition and the designated composition of calculation must be zero. The designated exactitude of calculation is 0.00001%.

b. Reducing the cost of metallic materials to the lowest for the enhancement of economic effectiveness.

c. The calculation time must be short enough to satisfy the requirement of time limits in the smelting production. We set the time of solution for a single scheme as 5 seconds, and the optimization of a million schemes shall not be more than one minute; the calculation results are assured of improving the one time hit-rate to decrease the times of chemical analysis in furnace for further shortening of smelting time.

1.2 Customer first

It is realized in the following two aspects:

1. Enhancing of the service field and providing full-service for the melting production

   Earlier stage service: to guide the customers to make decisions on products to make sure the materials cost is the lowest.
   Intermediate stage service: to guide the use of materials to guarantee the lowest cost, composition accuracy and time saving.
   Final stage service: to search for new materials and further lower the cost; to search for insufficiency and strengthening the management.

2. To realize the real customization for users
The programming of the existing software limits the field of application (varieties of products and raw materials). We specified that the new system must be generally applicable for all the varieties of products and raw materials. There is no need to change the source program when the users want to develop new products or use the new materials. The new software provides the users with a lot of freedom.

2 The technological measures for the programming

In order to realize the objective of software programming, we carried out the following technological measures:

2.1 The ultimate objective function group—optimum proportion scheme

The existing calculation technique produces the solution of a single material (Only one material variety can be designated from each kind of materials), while the new system could produce the ultimate objective function group that is the optimum proportion scheme, which is provided with the lowest unit cost and zero deviation among the proportion schemes with possible compositions of material varieties to be selected. It possesses two best combinations—the best material variety combination, that is to select these material varieties from all the material varieties with no one less or more. And the best amount combination, that is each selected material variety must access the amount with no less or more.

The optimum proportion scheme is a set of ultimate objective function groups, which is locked by intermediary objective function group and processed through optimization calculation program.

2.2 Enlargement of the independent variables and establishment of intermediary objective function group

The new added independent variables for the new system:

\( W_{ij} \): Assembly of material varieties to be selected—material varieties to be selected from each kind of materials should be designated as many as possible; the material variety to be used should not be designated as the only one.

\( t_i \): Content of related elements, the content of \( i \) elements from \( j \) material varieties, which represents the conditions of the materials.

\( S_i \): Yield of the relative elements.

\( a_{ij} \): Unit price of each material to be selected.

The given condition is established, all the elements of calculation will make up an organic system, and the best material variety and amount will be locked by a set of intermediary independent variables assembly, which is called the intermediary objective function group indicated by \( Y_0 \):

\[
Y_0 = [n \cdot G_i \cdot Z_i \cdot g_i \cdot g_{1i} \cdot t_i \cdot S_i \cdot W_{ij} \cdot a_{ij}]
\]

In the equation: \( n \) —the number of elements to be adjusted; \( G_i \) —the amount of molten steel in furnace before adjustment; \( G_{1i} \) —the limited output of steel; \( Z_i \) —the loaded amount; \( g_i \) —the composition in furnace; \( g_{1i} \) —the designated composition; \( t_i \) —the content of alloy; \( S_i \) —the yield of main elements; \( S_{ij} \) —the yield of related elements; \( W_{ij} \) —same meaning as previously defined; \( a_{ij} \) —the intermediary objective function group, including \( a_{mn} \) —minimum unit cost, \( g_i \) —\( g_i < 0.00001\% \).

The deviation between adjusted composition and designated composition should be zero. \( Y_0 \) is not the ultimate objective function but it is locked by \( Y_0 \).

2.3 Establishing the operating program chain

In order to provide the optimum proportion scheme, we established an operating program chain made of 14 multiple step programs, and each step program contains some subprograms. Two multiple step programs will be connected by chain program, and corresponding mathematical model will be established on each program point. The optimum proportion scheme will be provided by driving operating program chain with the input of given condition.

The sketch map of the calculation program chain is shown in Fig. 1.

Fig. 1 Sketch map of the calculation program chain

2.4 Initial Scheme of Coordination

(1) Principle of coordination

All the materials to be selected have to be coordinated with all the material varieties for only once.

(2) Initial scheme

The initial scheme is the material proportion scheme of the materials to be selected in accordance with 1.1 coordination principles. The number of initial scheme is \( N \). There is \( j \) kinds of materials to be selected, and the number of material varieties will be \( Z_1, Z_2 \ldots Z_j \) separately. Then \( N=Z_1, Z_2 \ldots Z_j \).

2.5 Basic calculation

The calculation reveals the internal connection among the elements of calculation, and reconstructs the intermediary variables. It is the type of classification and derivation.

It is the base for running optimization calculation and general accurate calculation with one method.

The following is taking the intermediary variable, the theoretical output of steel \( G \) and coefficient \( K \) of composition adjustment as example to give a concise explanation.

\( G \): The amount of alloy and losses of elements are specified,
as the given condition is confirmed, the amount of adjusted molten steel will be a definite value that is called theoretical output of steel indicated as \( G \).

\[ K = f(n, G_x, G, g_{i}, g_{i}, t, s) \]

Comparing the constituents \( g_{i} \) before the adjustment and the specified composition \( g_{i} \), \( n \) constituents to be adjusted could be divided into two groups—high coefficient group and low coefficient group:

High coefficient group: \( p \) constituents (\( g_{i} > g_{i} \)) are high coefficient groups. The coefficient of composition adjustment is high and it is indicated as \( K_{p} \).

Low coefficient group: \( q \) constituents (\( g_{i} > g_{i} \)) are low coefficient groups. The coefficient of composition adjustment is low and it is indicated as \( K_{q} \).

The relation between the number of constituents is \( n = p + q \).

According to the ratio of \( G_{x} \) and \( G \), as well as the value between \( g_{i} \) and \( g_{i} \), the supplementary additive amount calculation would be divided into nine types of solution, which is shown in Table 1.

### 2.9 Optimization calculation

The optimization calculation is the process to produce the proportion scheme of the lowest cost from the possible proportion schemes of materials to be selected, the calculations are divided into primary calculation and secondary calculation. The primary calculation is the process to produce the proportion scheme of the lowest cost from the initial schemes; the provided optimization proportion scheme is the primary optimum calculation. If the cost of the primary scheme is possible to be reduced, the ultimate optimization calculation is the optimum proportion scheme, and its unit cost is the lowest and the deviation of the composition is zero. The optimum proportion scheme may be that each variety contains one material, or each variety contains more than one kind of material.

### 2.10 Special treatment

The following cases need to be solved by the new system through special treatment.

1. **The complete data system**

   In order to make the volume of the molten steel remain the same, the solvent need to be added, while the offset calculation is being carried out. When the calculation ends, the newly added solvent need to be eliminated. This process is called elimination calculation.

2. **NEG calculation**

   Sometimes, the calculated amount of some kind of material could be negative, which is caused by higher related amount. It could not be realized in the production, and the calculation to eliminate the negative value of the material is called negative value treatment.

3. **Assignment calculation**

   The collocation application of high carbon material and low carbon material makes the composition of carbon reach the designated value. The calculation to confirm the amount of each material is called assignment treatment.

   The optimum proportion scheme is locked by the intermediary objective function group; it is finally obtained by special treatment through optimization calculation, etc.

### 2.11 Incarnating the concept of customers first

It is reflected in two respects: one is to report the complete data system to supply strong data support for production and calculating activities of customers; the other is to realize the real self-determination of customers.

1. **The complete data system**

   The new system reports not only the amount of each kind of material, but the six kinds and twenty items of calculation data including the added amount, it is a complete data system as shown in Table 2.
The complete data system provides strong support for the molten steel production, and this realizes the complete service.

(2) Real customization

During the programming, the existing software requires the designated variety of steel and raw materials—limited field of application.

While the user develops the new variety of steel and the new materials, he has to ask the help from the supplier. The new system is generally applicable for all the materials, which realizes the real customization.

3 Solution Examples

Example 1: Solution example for supplementary additive amount (selected from “Electric Arc Furnace Steel Production”, edited by Shanghai No.5 Steel Plant)

Known conditions: Variety of steel 1Cr18Ni9Ti, quantity of molten steel in furnace 16.2 t, and the other conditions are listed in Table 3.

Solution: How much is the supplementary additive amount of FeCr, electrolytic Ni and FeTi separately?

Calculation results: The original work processes the solution by the method of supplementary additive factor—the adjusted composition of the three elements all have deviations: Cr+0.0767%, Ni+0.0462%, Ti+0.0022%, and high consumption of alloy.

The new system processes the solution—the adjusted composition of the three elements can be accurate to 0.0000% and per ton molten steel can saves alloy: 2.026 kg for FeCr, 0.778 kg for electrolytic Ni, 0.121 kg for FeTi.

Example 2: Example of burden calculation (selected from “Induction Furnace Melting” by Wang Zhendong, et al.)

Known conditions: Steel variety 0Cr18Ni12Mo2 amount of furnace charge 165 kg and other conditions are listed in Table 4.

Solution: The amount of the seven materials has to be calculated for the designated composition.

Calculation results: Composition (wt-%): Cr 19.11368, Si 0.60306, Ni 12.07180, Mn 1.70828, Mo 2.51496, C 0.06517. The 99.40523 kg molten steel volume is produced from 100 kg furnace material, which makes the manufacturing cost of steel 14226.22 yuan/t.

Examples 2.1 – 2.3

Take the adjusted composition from the original article as the calculation composition, and the 100 kg molten steel amount of furnace material as the limited steel amount to designate three combinations of materials.

(1) Example 2.1: Combinations of materials is the same as the Table 3 Other conditions of 1Cr18Ni9Ti

<table>
<thead>
<tr>
<th>Element</th>
<th>Component in furnace, wt-%</th>
<th>Calculation component wt-%</th>
<th>Alloy content wt-%</th>
<th>Yield %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>17.10</td>
<td>17.60</td>
<td>65</td>
<td>95</td>
</tr>
<tr>
<td>Ni</td>
<td>10.35</td>
<td>10.60</td>
<td>99</td>
<td>98</td>
</tr>
<tr>
<td>Ti</td>
<td>0.50</td>
<td>0.50</td>
<td>30</td>
<td>60</td>
</tr>
</tbody>
</table>

Table 4 Burden of 0Cr18Ni12Mo2

<table>
<thead>
<tr>
<th>Element</th>
<th>Calculation content, wt-%</th>
<th>Alloy content, wt-%</th>
<th>Yield %</th>
<th>Name of materials</th>
<th>Chemical composition, wt-%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>19.00</td>
<td>69.80</td>
<td>98</td>
<td>FeCr</td>
<td>0.06 0.39 - 69.80 - -</td>
</tr>
<tr>
<td>Ni</td>
<td>12.00</td>
<td>99.90</td>
<td>100</td>
<td>Electrolytic Ni</td>
<td>0.03 - - - 99.9 -</td>
</tr>
<tr>
<td>Mo</td>
<td>2.50</td>
<td>58.80</td>
<td>98</td>
<td>FeMo</td>
<td>0.17 0.05 - - - 58.8</td>
</tr>
<tr>
<td>Si</td>
<td>0.60</td>
<td>44.50</td>
<td>90</td>
<td>FeSi</td>
<td>0.05 44.5 0.38 - - -</td>
</tr>
<tr>
<td>Mn</td>
<td>1.70</td>
<td>99.38</td>
<td>95</td>
<td>Electrolytic Mn</td>
<td>0.03 - 99.38 - - -</td>
</tr>
<tr>
<td>C</td>
<td>0.06</td>
<td>-</td>
<td>-</td>
<td>Reverts</td>
<td>0.10 0.78 1.56 16.60 8.70</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pure iron</td>
<td>0.03 0.03 0.10 - - -</td>
</tr>
</tbody>
</table>

The complete data system provides strong support for the molten steel production, and this realizes the complete service.

Table 2 The data system of the new system

<table>
<thead>
<tr>
<th>A. Optimum proportion scheme</th>
<th>B. Chemical component</th>
<th>C. Amount of molten steel (weight of molten metal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Solvent (e.g. Pure iron, etc.)</td>
<td>10. Adjusted component of minimal element</td>
<td>13. Actual steel output</td>
</tr>
<tr>
<td>4. General amount of reverts</td>
<td></td>
<td>15. Added amount</td>
</tr>
<tr>
<td>5. Maximum amount of reverts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Pig iron</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. C increment agent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Ore</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

D. Loss amount | E. Cost | F. Theoretical data
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>17. Loss of solvent</td>
<td>19. Lowest unit cost of metal and alloy</td>
<td>of component adjustment</td>
</tr>
</tbody>
</table>
one of the original article.

(2) Example 2.2: The 360 kinds of proportion schemes are collocated from the 21 kinds of materials.

(3) Example 2.3: The 1,123 kinds of proportion schemes are collocated from the 41 kinds of materials.

Solution: the optimum proportion scheme.

Calculation results: Adjusted composition: six elements (Cr, Ni, Mo, Si, Mn, C) from three examples. Each element is accurate to 0.00000%.

Cost: the cost of example 2.1 is the same as the one of the original article, as the materials are the same. The cost of example 2.2 is 389 yuan/t lower than the one of the original article. The cost of example 2.3 is 641 yuan/t lower than the one of the original article. See Table 5 for details.

Example 3: Production example

Certain plant smelts certain brand stainless steel. While Ni, Mn, Si and Mo meet the specification, the final adjustment needs only to modulate Cr from 12.41wt-% to 13.00wt-%. It is known that the content of Cr in FeCr is 60.80wt-%, the amount of molten steel in furnace is 2 t, and the recovery ratio of Cr is 97%. What is the supplementary additive amount of FeCr? Calculation results are that the supplementary additive amount of the new system solution is 25.534 kg. As there is a little inaccuracy in weighting the materials, the actual adjusted composition is 12.99%.

4 Conclusions

(1) The new system realizes the accurate calculation, and the calculation composition is accurate to 0.00001%, which makes a great leap from the approximate calculation to the accurate calculation for the calculation of composition adjustment.

(2) The new system extends the objective function from the amount of designated variety to the optimum scheme of varieties and optimum scheme of use level, insuring the accurate composition calculation and the lowest cost, which realizes the integration of technology and economic effectiveness.

(3) The complete data system provides strong support for the molten steel production, which realizes the complete service.

(4) The new system is generally applicable for the varieties of products and raw materials, which realizes the real customization for the users.

(5) The advanced performance and the high practical ability of the new system are recognized by the factories. The new system has been applied in Shenyang Research Institute of Foundry.

References


