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The Method of Analysis of Assembly Work Based on the Fastener Method*

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This paper deals with two methods of analyzing and planning an assembly work. First, we propose a method of breaking the assembly work down into its work elements, in which all parts constituting the product are classified into unit groups based on the fastener method in assembling (e.g. bolted joints, riveted joints, shrinking and pressing fits, and so on). As a result, the assembly work is broken down into its work elements which fasten the parts in each group. At the same time, a problem of precedence relation among them arises.

Secondly, we propose an assignment method in which the number of stations is determined, and the work elements are assigned to the work stations in a single assembly line as the efficiency of line balancing alters as a variable.

By using the methods proposed here, we could analyze the assembly work consistently through breaking it down into work elements and assigning the work elements to work stations.

1. Introduction

Assembly work is defined as the operation of fitting or putting together two or more parts and making up a semi-complete or complete product. Designing and planning the most practical and economical production process, therefore, requires an analysis of assembly work. For analyzing the assembly work, the total work content is divided into minimum rational work elements based on the product design. Then the time duration of the work elements can be determined by time study and method study. The precedence restrictions are examined which are constraints imposed on the order or time sequence in which the work elements can be performed. Thus a list of the assembly work elements can be obtained. And then the assembly line of the product is planned and set up according to production volumes, operators, facilities and/or machines on the basis of the production schedule⁽¹⁾⁽²⁾.

By the way, much attention has recently been drawn to the problems of analyzing assembly works. The precedence diagram⁽³⁾⁽⁴⁾, the precedence matrix⁽¹⁾, the precedence list⁽⁵⁾, and the assembly chart⁽⁶⁾ have been used for the method to indicate the precedence restrictions among the work elements. Further, various methods of assembly line⁽⁷⁾⁽⁸⁾ balancing have been developed and utilized, e.g. CALB⁽⁹⁾, CADAP⁽²⁾. But it seems that

dividing the total assembly work into several components has only been done empirically by experienced industrial engineers.

Now, in the CAD-CAM system⁽¹⁰⁾⁽¹¹⁾ are being developed the methods of automated design and production systems by using the computer⁽⁹⁾⁽¹²⁾. In these methods, the characteristics of the parts constituting the product are analyzed in order to process similar parts economically. For example, the group technology⁽¹³⁾ and the fastener methods⁽¹⁴⁾⁽¹⁵⁾ are a well-grounded method of classifying the parts.

In this paper, we propose a method which divides the parts constituting the product into unit groups by the fastener methods. So the assembly work is broken down into several work elements. Further, a problem of precedence relations among them arises from the relations among groups of parts. The list of work elements and the precedence restrictions among them are used for the assembly line balancing. We call this method "the functional unit developing method".

The assembly line balancing is a procedure to assign work elements to each work station in a moving manufacturing line by using the precedence restrictions. The basic problem involved here is how to balance the workload at each station and to make the work content as close as possible to the cycle time of the line. Various methods have been developed and utilized to solve this problem. In these methods, either the number of stations or the cycle time must be determined. The number of stations is restricted by personnel, machine, tool, work area and so on. The cycle time is calculated by the production volume and time. When the number of stations is given, the assignment is determined so as to

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minimize the cycle time. Or under a given cycle time, the number of stations is minimized. As a result, the efficiency of line balancing, that is, the rate of the total work time to the total cycle time of every station is raised⁽⁷⁾. But in practice it is desirable to obtain a work assignment which shows the highest efficiency of line balancing under all possible combinations of stations and the cycle time. Therefore, we propose a method of line balancing in which the efficiency of line balancing is regarded as an independent variable.

2. Design of the assembly line by the methods proposed

2.1 The assembly work division method

The assembly work can be defined, in a narrower sense, as fastening together two or more parts based on the fastener method (e.g. bolted joints, riveted joints, shrinking and pressing fits, etc.)⁽⁸⁾. So all component parts constituting the product can be classified into groups by the fastener methods. And if fastening the parts together is regarded as a work element in each group, we can divide the assembly work into work elements according to a definite rule as follows.

2.1.1 The fastener method

Table 1⁽¹⁴⁾ shows the fastener methods, which are classified into four categories according to the completed shapes, (1) a fixed fastener which can be disassembled, (2) a fixed fastener which can not be disassembled, (3) a movable fastener which can be disassembled, and (4) a movable fastener which can not be disassembled. In these forms of fastening, there are particular parts (i.e. the fastener parts) which play the role of completing the joint, for example, bolts and nuts in bolted joints, rivets in riveted joints, E-shaped ring joints, etc. With special attention paid to the fastener parts, all parts are classified into unit groups by the fastener methods and thus the relations among groups can be obtained.

2.1.2 The functional unit

The parts in each group are joined together by each fastener method. Then the joined parts have a particular function which is different from that of component parts. So we call this a functional unit. The number of functional units is equal to the number of fastener methods in the production. Further, the division of the total assembly work can be done according to the functional units based on the fastener methods.

Table 1 The fastener method

Completed shapes		Code	Examples
fixed fastener	disassembled	Fd	screwed or bolted joints, key, spline, wedge
	not disassembled	Fnd	pressing fits, riveted joints, welding, brazing, soldering
movable fastener	disassembled	Md	bearing and shaft, tool slide, E-shaped ring, spring
	not disassembled	Mnd	races and balls of ball bearing

Table 2 The notations for the developing chart of the functional unit

Name	Notation	Explanation
part	the number of the part	the component part which is supplied to the assembly process under consideration
functional unit	the number of the functional unit	the unit which is fastened together in the assembly process
group of parts fastened together	the code of the fastener method the group of parts	the group of parts which are fastened together by the fastener method
common part or functional unit	c c	the same part or functional unit which is used in two or more fastenings

Table 3 A functional unit list

Functional unit	Contained functional unit	Contained part	Time durations
f_1	$f_{11} \dots f_{1m_1}$	$u_{11} \dots u_{1n_1}$	t_1
$\vdots$	$\vdots$	$\vdots$	$\vdots$
f_i	$f_{i1} \dots f_{ij} \dots f_{im_i}$	$u_{i1} \dots u_{ij} \dots u_{in_i}$	t_i
$\vdots$	$\vdots$	$\vdots$	$\vdots$
f_l	$f_{l1} \dots f_{lm_l}$	$u_{l1} \dots u_{ln_l}$	t_l

2.1.3 A developing chart of the functional unit

A developing chart of the functional unit tries to show the parts, the fastener methods, and the functional units, respectively. The assembly process through component parts to the completed product can be seen in the chart. Table 2 shows the notations for the chart. The chart consists of parts, functional units, groups of parts fastened together, common parts, and common functional units.

2.1.4 A functional unit list

A list of functional units shows respectively the functional units, the parts and other functional units constituting each functional unit, and the time durations. The number of all functional units is given in the first column. In the next column is given the number of other functional units constituting them. The parts constituting them are listed in the third column. Table 3 shows a general list of functional units.

By the way, as the functional units correspond to the work elements, the list can be used as a list of the assembly work elements.

2.1.5 The precedence relations among functional units

The relations between the two functional units, f_i and f_j , are as follows.

- (1) $f_i \in f_j$: f_i is contained in the second column of f_j in the list. In this case, f_i must precede f_j .
- (2) $f_i \cap f_j \neq \emptyset$: Both f_i and f_j have the same part and/or same functional unit in each second and/or third column of the list, that is, f_i and f_j have common parts and/or common functional units. In this case, f_i and f_j can not be fastened at the same time.
- (3) $f_i \cap f_j = \emptyset$: In this case except (1)(2), f_i and f_j can be fastened in parallel.

2.1.6 A precedence list and a precedence diagram

A list of functional units shows the essential data in assembly line balancing, that is, the work elements, precedence restrictions among them, parts used, and time durations. Precedence restrictions among work elements are given in the first and second column of the list. The functional units, which are given in the second blank column, need not be preceded by any other units.

A precedence diagram can be made by this list. It is a basic tool for analysis in assembly line balancing. Therefore, the list of functional units contains all the information on the work elements for the purpose of line balancing. Even a person unfamiliar with the actual product can devise a list by the work division method proposed here.

2.2 The line balancing method

In general, the efficiency of line balancing⁽¹⁷⁾, which is indicated by the following E_b , has been used in order to evaluate the work assignment on the progressive assembly line.

$$E_b = \frac{T}{N \times P} \times 100 \quad \dots\dots\dots (1)$$

where E_b = the efficiency of line balancing

T = the total work content time
 N = the number of work stations
 P = the cycle time to traverse N stations, the maximum operation time at each station.

The assignment of the work elements is ideal at $E_b=100\%$, as there is no loss time in the line. E_b is regarded as a dependent variable in Eq. (1).

Therefore, we propose a method of line balancing in which E_b is regarded as an independent variable to get the optimum solution. The procedure proposed here is as follows.

Step 1. The minimum requirement of E_b ; E_{bmin} , and the constant value d of reducing E_b are given.

Step 2. The theoretical maximum number of stations N_{max} is calculated from the the given E_{bmin} as follows.

$$N_{max} = \left[\frac{T}{P_{min}} \times \frac{100}{E_{bmin}} \right] \quad \dots\dots\dots (2)$$

where P_{min} = the theoretical minimum cycle time

$$P \geq t_{max}, P_{min} = t_{max}$$

t_{max} = the maximum work element time

$[]$ = integer a when $a \leq [] < a+1$

: Gaussian symbol.

Then the possible range of N extends from N_{max} to 2. The following steps are applied to any N in this range. At first, N is given as N_{max} . Go to next step.

Step 3. E_b is given as the ideal value of 100. Go to next step.

Step 4. E_b is reduced by d , that is,

$$E_b = E_b - d. \text{ Under the given } E_b \text{ and } N,$$

the cycle time P is calculated by

$$P = \frac{T}{N} \times \frac{100}{E_b} \quad \dots\dots\dots (3)$$

Under the given combination of (N, P) , go to next step.

Step 5. At first, select the work elements which have not the preceding elements in them. Next, add to them the work elements which have only the assigned elements as the preceding ones. This step can be done by using the functional unit list. Go to next step.

Step 6. Select the work elements, which have less time than the remaining cycle time of the station, from among the group of work elements selected

at step 5. If any work elements can be selected here, then go to step 7. If no work element can be selected here, proceed to the next station and repeat the same step. If the last station has been examined, go to step 8.

Step 7. Assign to the station a work element having the maximum work time in the elements selected at step 6. Subtract the work time from the remaining cycle time of that station and eliminate the assigned work element from among the group selected at step 5. Then return to step 5.

Step 8. If all work elements have been assigned, a solution can be obtained. The efficiency of the assignment thus obtained is calculated by

$$E'_b = \frac{T}{N \times C} \times 100 \dots \dots \dots (4)$$

where C = the maximum station time
 $C < P$.

Then we search for an assignment which shows the maximum efficiency, because of $E_b < E'_b < E_b + d$. So let $E_b = E'_b$ and $P = C$, return to step 5 under a new combination of (N, P) . If one or more work elements remain and a solution under N is not obtained, return to step 4. If any solution under N is obtained, reduce N by 1, that is, $N = N - 1$. When N equals to 1, stop the procedure. If not, return to step 3.

3. Applications to actual product

3.1 A small electric switch as a simple example

We use a simple small electric switch shown in Fig. 1 in order to describe the method proposed here. Three figures may be used for the number of parts for identification in the computer programs (e.g. 100:small screws, 200:bolts, 300:washers, 400:nuts, 800:special parts). And two figures may be used for the number of functional units. In this switch, screwed joints are used for the fastener method. Then the component parts are classified into several units of groups by watching the screws and nuts.

The functional unit 01 is fastened together with 802, 803, 804, 805 and 306 by screwed joints having two small screws 101 and two nuts 407. 02 is fastened together with 408 and 309 as well as with 802 and 810. 03 is fastened together with 02 (the combination of 802, 408, 309, 810) as well as with 811 and 803. 04, 05, and 06 are fastened together with 313 as well as with 112 and 805. So all parts constituting this

switch are classified into six functional units based on the fastener method. Then a chart of developing the functional units can be drawn as shown in Fig. 2. Table 4 shows a list of functional units. In the list, time durations of the units are calculated by Methods Time Measurement. Only the functional units 03 has the functional unit 02 in the second column of the list, so 02 must precede 03. Figure 3 shows an arrow diagram indicating the precedence restrictions among units. But both 01 and 02 have the common part 802. Both 01 and 03 have 803, and 01, 04, 05 and 06 have 805 as the common parts.

We assigned six work elements to work stations by the line balancing methods proposed. The processes were as follows.

It is said that the assembly line must have more than 80% efficiency. So in step 1, we gave a value of 80% to E_{bmin} and 5 to d , which is the rate of reducing E_b . By using Eq. (2) in step 2, N_{max} was calculated as follows.
 $N_{max} = [T \times 100 / t_{max} / E_{bmin}] = [91.2 \times 100 / 32.3 / 80] = 3$.
Then put $N = 3$ and $E_b = 100$ in step 3. In step 4, $E_b = E_b - d = 95$ and $P = T \times 100 / N / E_b = 32.0$ by Eq. (3). Under $N = 3$ and $P = 32.0$, steps 5~8 were done, but a solution could not be found. Then returned to step 4 and $E_b = E_b - d = 90$ and $P = 91.2 \times 100 / 3 / 90 = 33.77$. Under $N = 3$ and $P = 33.77$, steps 5~8 were done, and a

Fig. 1 The assembly drawing of a small electric switch

Fig. 2 A developing chart of the functional units of a switch

solution could be found, in which 01 was assigned to station 1; 02, 03, 04 to station 2; and 05, 06 to station 3. $C=33.7$ of the time of station 2 and $E'_b=90.2$. Under $N=3$ and $P=33.7$, another solution could be found, in which 01 was assigned to station 1; 02, 04 to station 2; and 03, 05, 06 to station 3. $C=32.3$ of the time of station 1 and $E'_b=94.1$. Under $N=3$ and $P=32.3$, no assignment was done.

Next put $N=3-1=2$, return to step 3 and $E_b=100$. In step 4, $E_b=100-5=95$, $P=91.2 \times 100 / 2 / 95 = 48.0$. Under $N=2$ and $P=48.0$, steps 5~8 were done. A solution could be found in which 01, 04 were assigned to station 1; and 02, 03, 05, 06 to station 2. $C=46.3$ of the time of station 2 and $E'_b=91.2 \times 100 / 2 / 46.3 = 98.5$. Under $N=2$ and $P=46.3$, no solution could be found. As $N=N-1=2-1=1$, the procedure was stopped. As a result, the highest efficiency of line balancing was 98.5% under $N=2$ and $P=46.3$.

We assembled this switch on the moving assembly line⁽¹⁰⁾. We regarded two functional units, 02 and 03, as one work element. In the work assignment of three work stations, 01 was assigned to station 1; (02+03) and 04 to station 2; 05 and 06 to

Fig. 3 An arrow diagram of the switch

station 3; and the switch was produced. By according to the methods proposed, E_b became higher by 3.9%.

3.2 The case of two other actual products

One of the actual products mentioned here is an industrial electric timer (product A). Product A consists of 26 kinds of parts. The fastener methods are two spring-joints, one soldering, and six screwed joints. Table 5 shows the list of the functional units for product A. We searched for time durations with Video Tape Recorder in the present line. The line balancing method proposed was applied by using Table 5. The optimum assignment under six work stations is shown in Fig. 4, as compared with the present line at six work stations. The cycle time of the new line is lower than that of the present one, which is reduction from 89.9DM to 82.1DM. And the efficiency of line balancing becomes higher by 7.9% than that of the present one. The new E_b is 91.6% and the present one is 83.7%.

The other product was the subassembly of a motorcar (Product B). Product B

Fig. 4 A pitch diagram of Product A

Table 4 A functional unit list of the switch

Functional units	Contained functional units	Contained parts	Time durations
01	02	101 802 803 804 805 306 407	32.3 DM
02		802 408 309 810	15.3
03		811 803	5.8
04		112 313 805	12.6
05		112 313 805	12.6
06		112 313 805	12.6

Table 5 A functional unit list of Product A

Functional units	Contained functional units	Contained parts	Time durations
01	01	105 804 802 803 801	16.2 DM
02		107 806	16.7
03	02	808 809	13.7
04		806 810 811 812 813	19.5
05	03	814 815	10.7
06		816	19.8
07	04 05	119 817	18.3
08		121 820	15.5
09	03	124 822 823	18.5
10		822 825	40.7
11	08 09 10	127	37.8

Table 6 A functional unit list of Product B

Functional units	Contained functional units	Contained parts	Time durations
01		803 802 801	27.52 DM
02		204 801 805	19.35
03	02	515	9.00
04		801 813	7.33
05	01 03	806	7.80
06	05	807 808	8.17
07	06	809	8.55
08	06	814	11.72
09	06	512 511 510 511	17.67
10	06	512 511 510 511	17.67
11	07 08 09 10	516	5.32

n.b. 515:grease, 516:pen

Fig. 5 A pitch diagram of Product B

consists of fourteen kinds of parts. There are nine functional units, that is, one bolted joint, three spring-joints, two coupling-joints, one pressing fit, and two rubber-joints. Further, there are two other works, that is, greasing and making an inspection of assembly with a pen. The works of adjusting and testing may be regarded as the functional units by giving the number to materials and subassemblies used. Then the method proposed can process these works. A list of functional units added with the two works is shown in Table 6. The assembly line balancing can be done by the method proposed using the data of Table 6. The optimum assignment has four work stations, 34.8DM of the cycle time, 96.9% of the efficiency of line balancing, as shown in Fig. 5.

4. Conclusion

In order to obtain the assembly work elements and the precedence restrictions among them, we propose a functional unit developing method in which the parts are classified into unit groups based on the fastener method and the total work content is divided into work elements. Further, we propose a line balancing method in which the efficiency of line balancing is regarded as an independent variable. And the number of stations and the cycle time of the line are determined. As a result, we obtain the optimum assignments of work elements for the assembly line.

The characteristics of the methods proposed here and the applications of them to actual assembly process are as follows.

(1) In the procedure of the functional unit developing method, all component parts

assembled in an assembly process are divided into groups based on the fastener method. The groups of parts are called functional units. Further, the total assembly work can be divided into work elements by functional units. The precedence restrictions among work elements can be obtained from the relations among functional units.

(2) In an assembly line balancing based on the work elements, the possible range of the numbers of work stations is determined from the minimum requirements for the efficiency of line balancing and the maximum work element time. Then the restrictions of the cycle time are calculated by varying the efficiency. By assigning work elements under the condition, an optimum assembly line is obtained.

(3) As a result of the application of the methods proposed, it is made clear that we can analyze the assembly work consistently through breaking it down into work elements and assigning of work stations.

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