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Research on Energy Saving Dispatching of Forging Link Based on Number of Reheating Times

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Abstract. For forging process in the production of high energy consumption, this paper proposes an energy-saving scheduling model. This article will take the forgings oven minimum hours minimum energy-saving scheduling for the production target of minimizing the idle time are established to aim at oven, for the purpose of energy saving. Using the Hungarian method to hierarchical model, and finally got the forging production of energy-saving of optimal production plan, and uses case to verify the feasibility of scheduling model.

1. Introduction

Forging industry is an industry with high energy consumption, and the energy consumption of forging production accounts for about 25% of the total mechanical industry. Therefore, it is urgent to study energy conservation research in the forging industry, and it is imperative to improve energy efficiency, reduce carbon emissions and improve the environment in the forging industry.

At the manufacturing system level, Somervell D[1] studied the infrastructure and energy consumption to ensure the proper functioning of production activities, and proposed an energy management system to monitoring these activities. Gong yunqi[2] established the energy consumption model of green manufacturing system. At the level of production process, S. Rahimifard[3][4] proposed a method to improve the efficiency of manufacturing system by increasing the proportion of theoretical energy consumption in each process of manufacturing process by calculating the theoretical energy consumption, auxiliary energy consumption and indirect energy consumption. Dai M et al. [5] proposed an energy efficiency model for flexible production line scheduling problems, with the shortest processing time and the minimum total energy consumption as the optimization goal. He Yan[6] established the hierarchical energy model of the mechanical manufacturing workshop from the perspective of machine tool components and production process, and studied different levels of energy consumption assessment methods. Wang Jian[7] studied the enterprise energy consumption process model based on Fuzzy Petri Net, and established an energy consumption analysis model.

This article will take the forgings oven minimum hours minimum energy-saving scheduling for the production target of minimizing the idle time are established to aim at oven, for the purpose of energy saving. Using the Hungarian method to hierarchical model, and got the forging production of energy-saving of optimal production plan, and uses case to verify the feasibility of scheduling model.



2. Forging process analysis

2.1. Definition of related parameters

This paper focuses on the forging process of free forgings, Figure 1 is a flow chart of the forging process of free forgings.

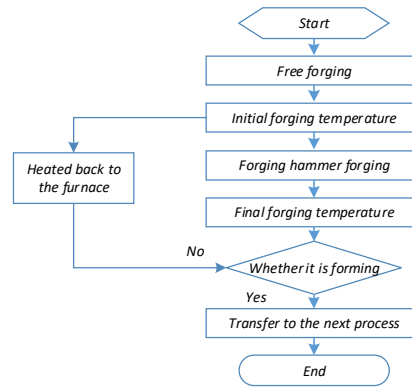


Figure 1. Free forging process flow chart.

First define some necessary parameters and instructions for this process.

- 1) Initial forging temperature T_{start} : The initial forging temperature of the forging;
- 2) Final forging temperature T_{end} : The final forging temperature of the forging;
- 3) Cooling time T_1 : The time during which the forging is cooled from the initial forging temperature to the final forging temperature, also called the forging cycle;
- 4) Cooling rate v : The speed at which the forging is cooled from the initial forging temperature to the final forging temperature;
- 5) Number of furnaces N : The number of times the forging needs to be reheated during the forging process;
- 6) Process forging time T_i : The time of each process of forging;
- 7) Process change time t_i : When the forging is forged, the change time between each adjacent process;
- 8) Forging hours T_2 : The time from the beginning to the completion of the forging is called the time of forging, excluding the heating time of the furnace. $T_2 = \sum_{i=1}^n T_i + \sum_{i=1}^{n-1} t_i$, n is the number of processes.

2.2. Forgings back to furnace analysis

Generally, the forging process in the free forging process includes upsetting, axial upsetting, punching, punch reaming and dressing. The following is analyzing the back to furnace situation of forgings in the forging process for these several processes.

1) When $T_2 \leq T_1$, forging hours are less than forging cycles, that is, when the forging is forged for the first time, the forgings have been forged before the temperature of the forging reaches the final forging temperature, so there is no need to return the furnace, as shown in (a) of Figure 2 below.

2) When $T_2 > T_1$, when the temperature of the forging reaches the final forging temperature, the forging has not been formed. At this time, the forging needs to be returned to the furnace at least once, and the actual number of furnaces is determined by $n = T_2 / T_1$ (How to reduce the number of return furnaces to save energy when the number of return furnaces is multiple). As shown in (b) of Figure 2 below, the forging is once returned to the furnace.

3) It takes a certain time to change between different processes during forging (referred to as time τ for short), and this time should not be included in the cooling time of the forging, that is, the forgings is constantly forging deformation throughout the cooling process.

4) If the replacement time is placed outside the cooling time, it will be that at the end of each round when some kind of forging process is completed. It is possible that the residual temperature after one round is greater than the final forging temperature. Therefore, it is necessary to comprehensively consider the location of the change time.

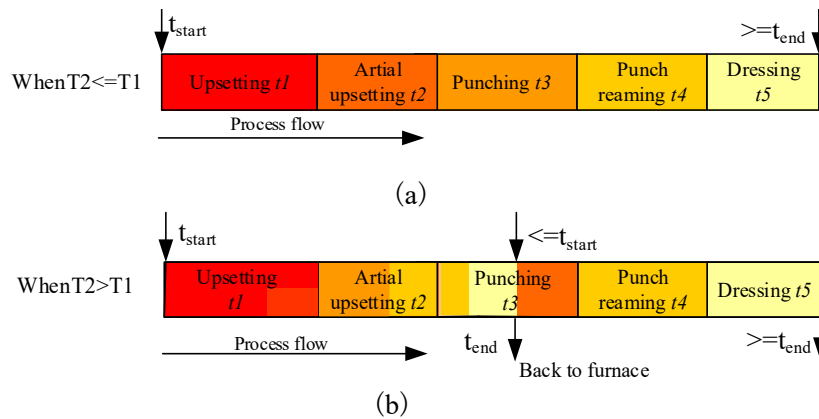


Figure 2. Schematic diagram of the number of times forgings back to furnace.

3. Forging scheduling model for the furnace backing times

For the purpose of energy saving, it is the less the better that the number of forgings back to furnace. So, it is possible to establish a scheduling model with the goal of the number of times of back to furnace. For a single forging, the forgings always be forged at one time without being back to the furnace. When the forging hour is more than the forging cycle of the forgings, the forgings must be back to the furnace, and the times of specific back to furnaces is determined by the forging hours and the forging cycle. As shown in the following formula.

$$N = \lfloor \frac{T_2}{T_1} \rfloor \quad (1)$$

In Equation (1), $\lfloor a \rfloor$ means taking an integer down from a , T_1 is the cycle of forging, and T_2 is the time of forging.

In the forging process, each time the furnace is returned, it will consume heating energy and construction period. If the number of times for forgings back to furnace can be reduced to a minimum, the energy loss can be reduced at this stage. As can be seen from the above formula, T_1 is generally only related to the material and environment of the forgings, so T_1 is constant in a certain forging environment. If T_1 does not change, the smaller the forging work time T_2 , the smaller the number of furnaces to be returned. Therefore, to reduce the total number of back to furnace for the forgings, it is necessary to minimize the forging hours of a single forgings

The objective is to minimize the times of forging back to furnace:

$$\min N' = \sum_{i=1}^m N_i = \sum_{j=1}^n \lfloor \frac{T_{2j}}{T_{1j}} \rfloor \quad (2)$$

Constraint:

- 1) Each forgings can only be forged on one type of equipment;
- 2) No waste appeared during the forging process.

In Equation (2), N' represents the total number of back to furnaces, n represents the number of forgings, and m represents the number of equipment.

4. Solve the forging scheduling model

For the model design solve method with the number of times of back to furnace as the objective function, we must first ensure that the result of the method must have a solution, and the Hungarian method can be used[8]. The Hungarian method consists of three sub-processes. First, A obtains the initial reduced square matrix, and then B determines whether the condition satisfies the optimal solution. If it satisfies, the optimal solution is obtained. If it is not satisfied, it enters C to obtain a new reduced square matrix. Then go to B to judge whether the condition is satisfied until the optimal solution is obtained. The specific steps of the model solving method with the number of times of back to furnace as the objective function are as follows:

Step1: According to the empirical data, the forging hours T2 between different types of forgings and each forging equipment, and the cooling time T1 of each forging are listed.

Step2: Create an $X_{m \times n}$ matrix with rows and columns in the matrix of the number of forging devices and the number of forgings, default $x_{ij} = \lfloor \frac{T_2}{T_1} \rfloor$.

Step3: Use the Hungarian method to find an optimal solution for this matrix and mark the element corresponding to the optimal solution with a '+'. The solution process of the Hungarian method is as shown in Figure 3.

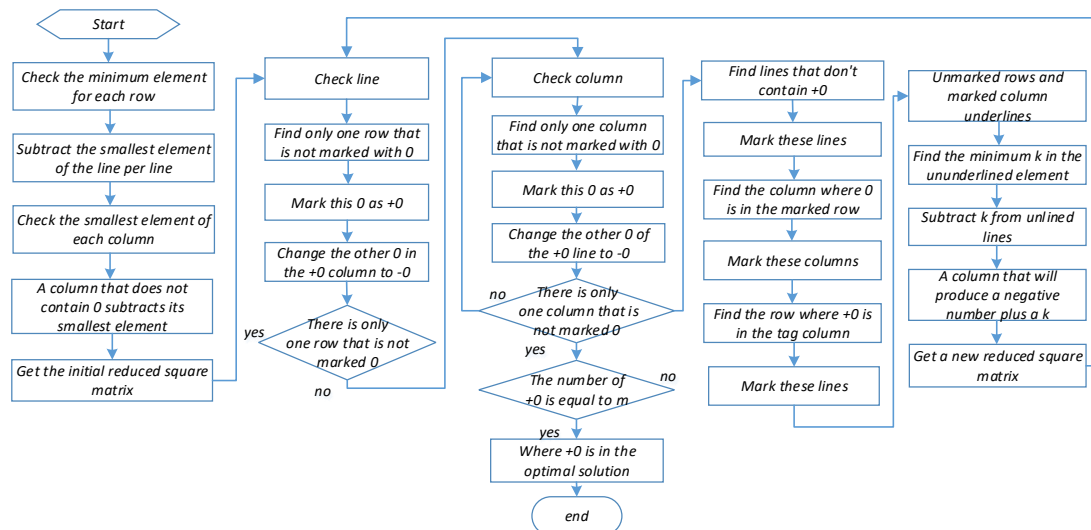


Figure 3. Hungarian method flow chart.

Step4: Compare elements in each row of the matrix $X_{m \times n}$ to each other, marking the smallest element '+'.

Step5: Change the value of the element marked '+' in matrix $X_{m \times n}$ to 1, and the other elements to 0, and the resulting matrix is X1.

5. Case study

5.1. Data preparation

According to the model established above, the following four kinds of data are needed to solve the model: each process time, process change time, back to furnace change time, and forging cycle (cooling time), which can be obtained by forging field measurement. There are four forging air hammers on the production line. The relevant information is shown in Table 1 below.

Table 1. Forging air hammer parameters.

Code name	model	Drop the quality (kg)	Anvil quality (kg)	Forging efficiency
M1	C41-100	100	1500	0.938
M2	C41-150	150	1870	0.926
M3	C41-200	200	2900	0.935
M4	C41-250	250	3000	0.923

In the actual production, there are four types of forgings of different shapes. The materials initial forging temperature is 1200 ° C, and the final temperature is 800°C. The working relationship between the forgings of these four types of forgings is shown in Table 2 below. The specific working hours of each steps are shown in Table 3, T is the Process forging hours, t is change time.

Table 2. Forging time of forgings under different forging equipment.

$J_{ij}(d, l, q)$	d	l	q	T2				T1
				M1	M2	M3	M4	
J_1	200	325	3	107 ₍₁₎	127.5 ₍₂₎	118.8 ₍₁₎	141.5 ₍₂₎	63
J_2	210	340	5	111.7 ₍₁₎	132.2 ₍₁₎	123.5 ₍₁₎	146.2 ₍₂₎	72
J_3	220	350	2	115.5 ₍₁₎	136 ₍₁₎	127.3 ₍₁₎	150 ₍₁₎	78
J_4	230	356	3	118.5 ₍₁₎	139 ₍₁₎	130.3 ₍₁₎	153 ₍₁₎	84

Table 3. Forging time of each process of forgings.

Forgings	equipment	Upsetting (min)		Drawing up(min)		Punching (min)		Cutting (min)		Trimming (min)	Working hours (min)
		T	t	T	t	T	t	T	t	T	T2
J_1	M1	21.3	1.7	20.1	3.3	18.6	3.8	20.7	3.4	14.1	107
J_2		22.0	1.7	21.3	3.3	19.6	3.8	21.6	3.4	15.0	111.7
J_3		22.5	1.8	21.8	3.4	19.9	3.9	22.3	3.5	16.4	115.5
J_4		23.0	1.8	22.4	3.4	20.6	3.9	23.1	3.5	16.8	118.5
J_1	M2	25.4	1.7	24.2	3.3	22.7	3.8	24.8	3.4	18.2	127.5
J_2		26.3	1.7	25.1	3.3	23.6	3.8	25.9	3.4	19.1	132.2
J_3		28	1.8	26.8	3.4	25.3	3.9	27.6	3.5	20.8	136
J_4		28.6	1.8	27.4	3.4	25.9	3.9	28.2	3.5	21.4	139
J_1	M3	23.8	1.7	22.5	3.3	20.9	3.8	23.1	3.4	16.4	118.8
J_2		24.7	1.7	23.4	3.3	21.8	3.8	24.2	3.4	17.3	123.5
J_3		25.5	1.8	24.1	3.4	22.5	3.9	25.0	3.5	18.1	127.3
J_4		26.1	1.8	24.7	3.4	23.1	3.9	25.6	3.5	18.7	130.3
J_1	M4	28.3	1.7	27	3.3	25.4	3.8	27.8	3.4	20.9	141.5
J_2		29.1	1.7	27.9	3.3	26.4	3.8	28.7	3.4	21.9	146.2
J_3		29.9	1.8	28.7	3.4	27.2	3.9	29.3	3.5	22.7	150
J_4		30.5	1.8	29.3	3.4	27.8	3.9	29.9	3.5	23.3	153

5.2. The number of times of back to furnace

It can be seen from Table 2 that $N=2$ when $M2-J_1$, $M4-J_1$, and $M4-J_2$, and $N=1$ when $M1-J_1$ and $M3-J_1$, and $N=1$ when $M3-J_2$, $M2-J_2$, and $M1-J_2$.

Table 4. Results of solving the model of number of times of back to furnace.

F	$M1$	$M2$	$M3$	$M4$
J_1	1(+)	2	1(+)	2
J_2	1(+)	1(+)	1(+)	2
J_3	1(+)	1(+)	1(+)	1(+)
J_4	1(+)	1(+)	1(+)	1(+)

Using the solution method given above can be obtained the results as shown in Table 4. According to the step5 of the modeling, an X1 matrix can be shown as follow. And the minimize number of the times of forging back to furnace N' is 13.

$$X1 = \begin{pmatrix} 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{pmatrix}$$

Using the solution method of the scheduling model aiming at the number of times of back to furnace, the solution of this model is obtained as follows: forging J1 can't forge on M2 and M4 equipment, J2 can't forge on M4 equipment, and other forgings can be matched arbitrarily with equipment.

6. Conclusion

This article analyzes the energy-saving dispatching research of the forging process in forging, establishes the scheduling model with the number of times of back to furnace, and gives the solution process for the model, and obtains the final forging scheduling scheme.

Acknowledgments

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