Iron and Steel Industry Electrical Power Consumption Petri Net Prediction Model

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Abstract

Currently, it is a global issue that iron and steel industries productivity surplus, which makes most of iron and steel companies struggle to survive. Electric energy is the largest energy consumption in the iron and steel enterprises, and electric energy saving can be a key factor to enhance competitiveness of enterprises. To better to learn and predicate enterprise's power consumption, based on the production process flow of iron and steel enterprises, this paper uses the method of hybrid timed Petri nets to build electric energy consumption prediction model. Prediction model calculates electric consumption based on rated power of motor, which consists of two parts, namely stationary operation state model Ⅰ and accelerated operation state model Ⅱ. This paper also studies Petri elements connection rules and electric energy consumption calculation method. Finally, this model is verified to be feasible and effective in the forecast of the steel rolling production line of Tang Steel Group with the examples. The research result has deep effects to energy management and planning.

Keywords

Iron & Steel Enterprises, Hybrid Timed Petri Nets, Electrical Consumption, Operate Steadily & Acceleratory Model, Prediction Model.

1. Introduction

Iron and steel companies will be the key industry to apply energy-saving during the 13th Five-Year Plan. Currently, it is the global issue that iron and steel industries productivity surplus, which makes most of iron and steel companies struggle to survive. The main energy consumption is power consumption in the iron and steel enterprises, and the most of production devices are driven by electric motors, such as rolling mill, high speed shears machine and converter. Driving motors of production devices run without load operation when there is no billet entering to the device, and accelerate when billet is entering to the device, which increase power consumption largely. Intelligent ammeters are widely used in the enterprises, and the values of which are read by production statistical personnel. In this situation, it plays the role of detecting for electric consumption, which is a behavior afterwards. Control mode of power consumption devices, such as edger and high speed shear machine, seldom use power to control frequency conversion, thus, it has great potential in electric energy saving, and the urgently need for electric consumption prediction model. It is helpful for reasonable planning electric consumption, increasing economic benefit, and promoting energy management.

There are many methods to establish energy consumption model for iron and steel enterprises. Multilevel input-output method: the method is based on compiling enterprises materials of input-output analysis table, then, calculating energy consumption value by algebraic expression of energy and non-energy input-output analysis table [1]. Now the popular method comes from the combining usage of input-output model and e-p analysis. The e-p analysis, namely diagnosis mathematical model of energy consumption bottlenecks, uses steel ratio and process energy consumption to measure the material and energy flows, respectively. The function of the model is to decompose the change in consumption per ton steel into the changes in steel ratio and process energy consumption, so that the two factors' effects can be separated, and thus the energy consumption bottlenecks can be found [2]. Green Manufacturing Model: the optimization mothed for steel production process is based on the function of steel production process for green manufacturing model [3]. Multi-view energy model: it is an architecture of information integration, functional integration and logical integration of enterprises energy system, and data view. Production process view and brunch plant view are realized by different modeling approaches, which provids the decision support for system energy conservation [4]. Analytic hierarchy process (AHP): AHP is a practical and mature evaluation method, which determines major and minor factors affecting energy consumption, and is useful to saving energy [5]. Hierarchical resource process model (HRPM) based on hybrid Petri nets (HPN): the method presents a transformation mechanism from HRPM to HPN, and it is a basic model to optimize the energy system according to different objective [6,7]. Ref. [6,7] presented an optimization model in consideration of the energy flow within the real steel production process. The optimized goals are steel production, energy efficiency and self-made gas surplus, and the optimized method is fuzzy linear programming method [8]. Fuzzy Petri net model (FPNM) is similar to HPNM, which is widely studied domesticly and abroad [9,10]. Energy consumption reliability evaluation model: it established a new assessment system of energy reliability, process energy efficiency ratio and similar degree to describe the level of energy consumption reliability. It realized to maximize energy efficiency in steel production process within given time under specific materials and process conditions [11]. Generic neutral energy consumption estimation model: It is an energy estimation model based on generic neural network algorithm to predict oxygen consumption. The method has small errors between prediction value and practical value [12]. Data mining method: it can effectively use the useful information from energy data mining to meet the requirements of steel production by energy data acquisition [13].

Ref. [6-10] used Petri nets method to calculate energy consumption in production process. Electric energy consumption is the aggregate of every equipment's consumption value, and each value of the energy equipments comes from electric meter installed. We also conducted the same research using the Petri nets method [14,15], and found some new problems as follows. Firstly, usually electric meter record the energy values within a segment, not an individual equipment. Second, it is inaccurate to predicts real-time data according to historical electric energy consumption data. Because of the different steel billet type and production yield, electric consumption differences in the same lines. Finally, motor is key machine of electric consumption, which is due to steel production technology characteristics. This paper proposes an effective hybrid timed Petri net method to predict electric consumption based on iron steel production technology and electric network.

2. Petri Nets Prediction Model

2.1 Introduction of Power Consumption Prediction Model

Batch process includes continuous and intermittent process in each of production cycles, Prof. Gu proposed that according to production characteristics and function, production chart model is divided into procedure, process and operation, which have a partial ordering relation. Furthermore, based on resources, production chart is modularized a series of sub process.

In our model, procedure is defined as a group of operations, which transform input materials into output product. It is basic elements of production activities, and Petri nets prediction model should have parameters, such as power consumption, production planning, and information, et al. Process is the instance of procedure, which is the basic unit for resources' scheduling and dispatch, and can describe dynamic behavior of production procedure. These processes have characteristics as: sequence, concurrency, synchronism and independence. Operation is an execution method of production activities aiming at controllability and observability. It can describes production activities in detail from energy consumption behavior, production safety monitoring, and billet tracking, et al.

In iron and steel enterprises system configuration of CIMS (Computer Integrated Manufacture System), operation is on the level of PLC (Programmable Logic Controller), which is also on the level of enterprise information monitoring system. The iron and steel production belongs to continuous process with its unique characteristics which differs from other continuous process enterprises. On one hand, some iron and steel lines, such as continuous casting and rolling line, and hot rolling line, belong to classical continuous production lines, which are not much difference from the other industry enterprises, for example chemical enterprises. On the other hand, hot rolling line has some unique characteristics. Motor is running in two states, stationary operation state and accelerated operation. Motor is running in stationary operation state when there is no rolling reginal, and enters into accelerated operation state when rolling regional is detected. Power consumption prediction model must contain these two states. And hybrid timed Petri nets just meet this demands, it is an effective tool for discrete event system.

As mentioned above, this paper is using hybrid timed Petri nets to predict production process power consumption under the condition of not changing production chart. The key electric equipment of production process is motor. According to motor running state, this paper divides power consumption prediction model into two parts, namely stationary operation state model Ⅰ and accelerated operation state model Ⅱ. Model Ⅰ is enough if production process electric consumption' equipment is not contain accelerated step, and model Ⅰ is emphasized in continuous production chart process. However, model Ⅱ emphasizes on added with power consumption caused by accelerated motor. It is a monitoring model for billet tracking.

2.2 Electric Energy Consumption Model Hybrid Timed Petri Nets Definition Presentation

Stationary operation state model Ⅰ and accelerated operation state model Ⅱ are defined as follows.

Model Ⅰ={P,T,V,Pre,Post,Token,Marking,t}.

P={PC∪PD }. PC is continuous places set, which is divided into continuous power (electric) energy consumption set PE and continuous materials set PM. This paper emphasizes power energy consumption on theoretical study, not materials prediction, hence, materials consumption values is not included. Here, continuous materials set PM only describes order relations of production procedure. PD : Discrete places set, which describes running state of equipment.

T is defined as continuous transitions in model Ⅰ, which is a span of stable power consumption of a set of equipments.

V is defined as instantaneous firing speeds of the continuous transitions T, which describes consumption of energy flow and transformation of materials flow.

Pre={Pre(PM,T)∪Pre(PD,T)}. Pre(PM,T) is the material input incidence arcs set, which describes materials entering into the equipment. Pre(PD,T) is the information input incidence arcs set, which indicates operation information on equipment.

Post={Post(PM,T)∪Post(PE,T)∪Post(PD,T)}. Post(PM,T) is the material output incidence arcs set, which describes materials exiting to the equipment. Post(PE,T) is the power energy consumption prediction arcs set, which numerical values is rated power electric consumption of individual equipment or group equipment's. Post(PD,T) is the information output incidence arcs set, which indicates operation information on equipment.

Token={0,1}, placed in discrete place indicating whether or not equipment is in running state. 0 denotes equipment stops, while 1 indicates running.

Marking is the positive real number contained in continuous place set PC, PE is the continuous power consumption places set, PE (t) is used to count the power energy consumption change over time, and initial state PE (0)=0. PM is the continuous material consumption places set, PM (t) is used to count the materials consumption change over time. Here, electric consumption is the only focus point in this paper, and the materials consumption is not given.

t: is the set of time functions, which are associated with time factors on running in Model Ⅰ, and has a clear correspond relationship with the time variables in Model Ⅱ.

Those symbols used in Model Ⅰ are summarized in Table 1.

Table 1 Corresponding symbols to model-building elements in Model Ⅰ

Elements	Elements 1	Elements 2	Symbol
P	P^C	P^E	◌
		P^M	◎
			○
T			▯
Pre			⟹
		$Pre(P^M,T)$	→
Post	P^D	$Pre(P^D,T)$	⇢
		$Post(P^E,T)$	⟹
		$Post(P^M,T)$	→
Token		$Post(P^D,T)$	•
Marking		{0,1}	positive real number
t			time functions

Model Ⅱ={P,T,σ,Pre,Post,Token,Marking,t(τ)}.

P={PC∪PD}. PC is continuous power consumption places set, which represents power consumption value when equipment is in accelerated running state. PD is discrete information places set, which indicates whether or not equipment is running in accelerated state.

T={TC∪TD}. T is used to indicate whether or not equipment is running in accelerated state. As stated above, steel and iron production process is a batch processes. Some equipments are running under the uninterrupted state, when the materials are continuously entering and exiting to the equipments, with continuous caster being such an example; while other equipments have its production cycle, namely the materials are entering and exiting the equipment cyclically, for example, the melting cycle of 150-300t converter usually is 30min. TC is used to expressed uninterrupted equipment set, these equipments are running under stationary operation state, without additional power consumption in Model Ⅱ.

σ is instantaneous firing quantity of discrete transition set, which represents power consumption quantities generated by motor acceleration.

Pre={Pre(PC,TC)∪Pre(PD,TD)∪Pre(PC,TD)}: input incidence arcs set. Pre(PC,TC): continuous arcs set, connected with equipment running without accelerating. Here, Pre(PC,TC)=1.0, and this default value only means production state continuous information without materials consumption information. Pre(PD,TD): discrete arcs set, connected with equipment which strips can be passed. Here, Pre(PD,TD)=1, and this default value only indicates whether strips can be passed equipment or not without strips production value. Pre(PC,TD): arcs set connected between continuous places and discrete transitions. These arcs are used to indicate state changing, namely equipment running under continuous stationary operation state to accelerated operation state.

Post={Post(PC,TC) ∪ Post(PD,TD) ∪ Post(PC,TD)}: output incidence arcs set. The meaning of Post(PC,TC) and Post(PD,TD) are similar to Pre(PC,TC) and Pre(PD,TD), no detailed explanations here. Post(PC,TD): arcs set connected between continuous places and discrete transitions. These arcs mean accelerated power consumption when equipments are running under accelerated operation state.

Token: stands for tokens in discrete places, is used to indicate whether equipment is running under accelerated operation state or not.

Marking=Marking{PE(t)∪PM(t)}: stands for marks in continuous place. PE(t): additional power consumption caused by motor accelerated operation. The default value of PE(t) is zero. PM(t): iron and steel products value, in this model value of power consumption is emphasized, and products value is neglected.

t(τ): τ is delayed time in prediction time t. There is a delayed time τ associated with discrete transition TD, and discrete transition can fire after delay time τ. Token in discrete place indicates accelerated producing time for strip, and this value is decided by length of strip and speed of motor. Billet tracking system is composed of speed (digital measuring-speed element) and position (phototube) detecting devices. When billet tracking system detect the top of billet, the counter sets “0”; and when detect the tail, the counter sets “τ”.

Corresponding symbols to model-building elements in Model Ⅱ is shown as Table 2.

Table 2 Corresponding symbols to model-building elements in Model Ⅱ

Elements	Elements 1	Elements 2	Symbol
P	P^C	P^E	◌
		P^M	◎
			○
T	P^D		⧈
	T^C		▯
Pre	T^D		⟹
	$Pre(P^M,T^C)$		⇸
	$Pre(P^C,T^D)$		→
Post	$Pre(P^D,T^D)$		⇢
	$Post(P^M,T^C)$		⟹
	$Post(P^E,T^C)$		→
	$Post(P^D,T^D)$		⇸
Token	$Post(P^C,T^D)$		
Marking	{0,1}		•
t(τ)	$P^E(t)$, $P^M(t)$		positive real number
			time functions

2.3 Connection Rules in Model

Prediction model Petri nets connection rules follows general rules referred in reference [16].

Rule 1. PC and PD can connect with TC in Prediction model Ⅰ, if there is an conflict between PC and PD, PD has priority over PC.

Comment 1. Rule 1 is used to indicate running information in Prediction model Ⅰ.

Rule 2. PD can not connect with TC in Prediction model Ⅱ.

Comment 2. Rule 2 is used to indicate continuous stationary production process in Prediction model Ⅱ.

Rule 3. The Pre-place of TD can be PC, and the post-place of TD can be PD, and vice versa. Namely, through discrete transition TD, continuous place PC can be transformed into discrete place PD, and vice versa.

Comment 3. Rule 3 is used to indicate the change of materials state, for example, molten steel is transformed into strip steel through continuous caster.

2.4 Running Rules in Model

Since prediction model Petri nets running rules follows the same general rules in reference [16], readers can refer [16] for more details. There are two rules needed to be pointed out.

Rule 1 (Synchronized Rule). Model Ⅰ and model Ⅱ run and stop at the same steps. Model Ⅰ and model Ⅱ are restricted by time functions $t(\tau)$. t is prediction time in the model Ⅰ, while τ is the delay time caused by motor acceleration, generally, $t>\tau$.

Rule 2 (Power Comsumption Prediction Algorithm). The total power consumption volume E is equal to the sum of the power consumption E1 in model Ⅰ and E2 in model Ⅱ.

Power consumption $E1=\sum Post(PE,T)\cdot V\cdot t$, which is consumption energy when equipment is running in the stationary operation state model Ⅰ. Here, Post(PE,T)=rated power×unit number is the rated power caused by motor running under stationary state. V is instantaneous firing speed of continuous transition. t is prediction time in the model Ⅰ.

Electric consumption $E2=\sum Post(PE,T)\cdot\sigma\cdot\tau$, which is consumption energy when equipment is running in the accelerated operation state model Ⅱ. Here, Post(PE,T)=equivalent rated power×unit number is the equivalent rated power caused by motor acceleration. σ is instantaneous firing quantity of discrete transition. τ is the delay time in model Ⅱ.

3. Case Study

3.1 Tang Steel Co., Ltd Case Study

Production technological process in 1810mm Hot Rolling Line of Tang Steel Co., Ltd is shown in Fig. 1.

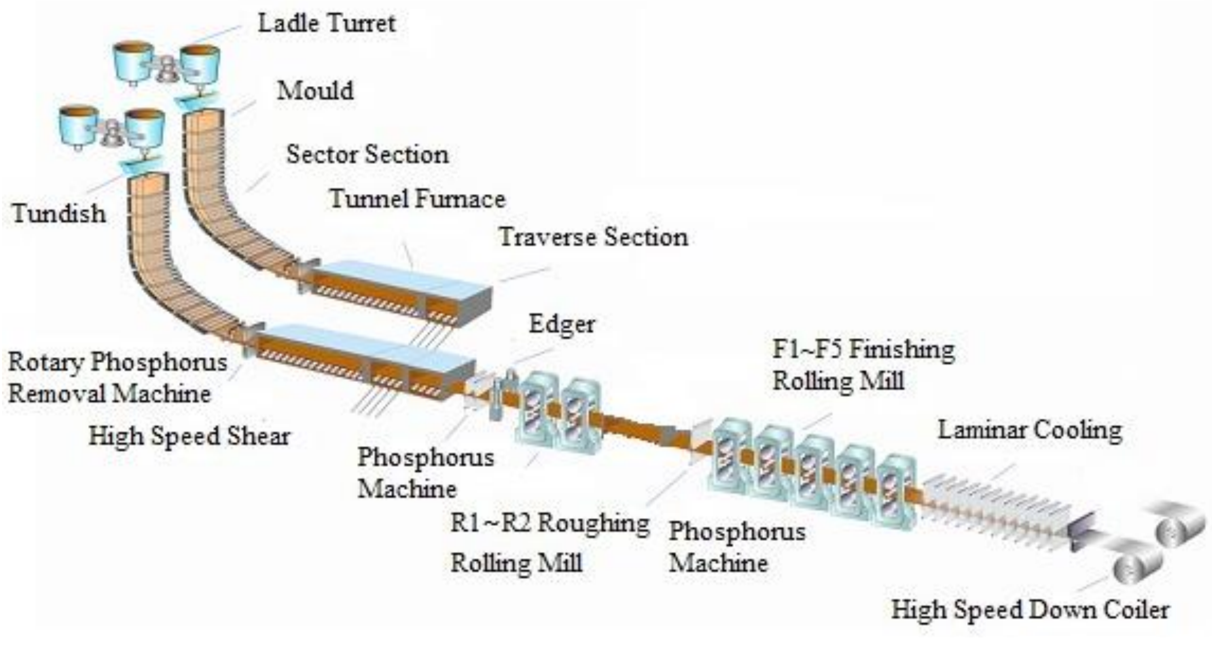
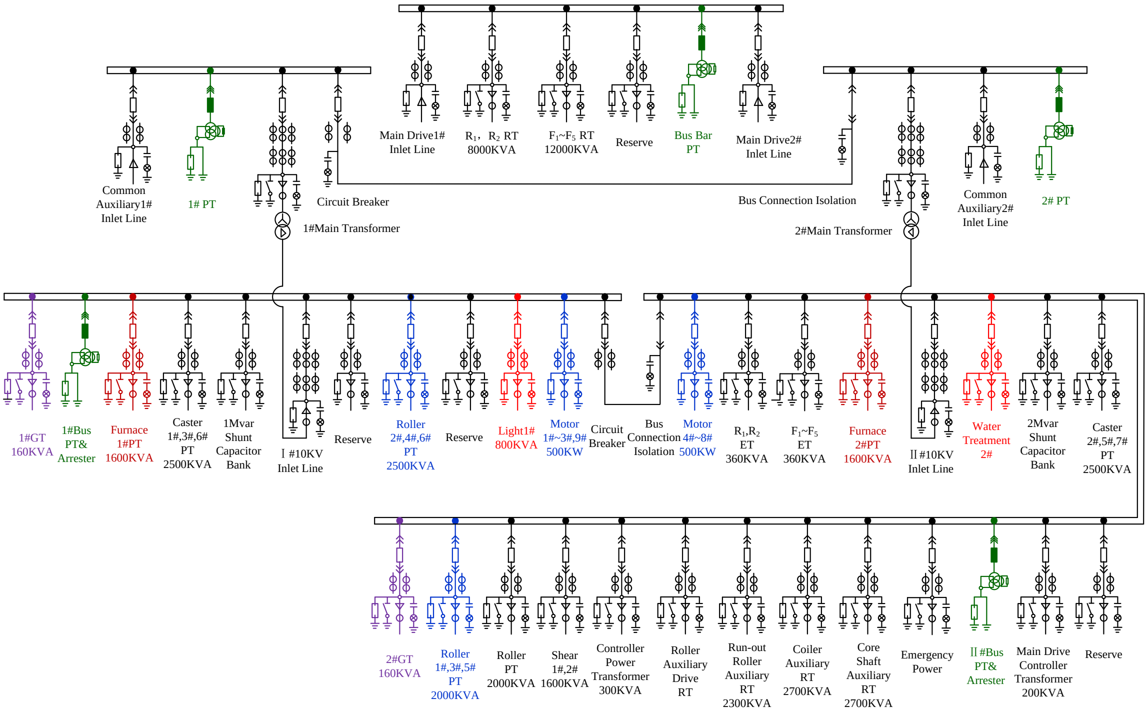


Fig. 1 Production technological process in 1810mm Hot Rolling Line of Tang Steel Co., Ltd

The key power consumption equipments are continuous caster(1#,2#), high speed shear(1#,2#), tunnel furnace(1#,2#), removal machine, edger, roughing rolling mill(R1,R2), finishing rolling mill(F1~F5) and high speed down coiler(CD1,CD2). Its high voltage system diagram is shown as Fig.2.



PT-Power Transformer; RT-Rectifier Transformer; GT-Grounding Transformer; ET-Excitation Transformer

Fig. 2 high voltage system diagram of 1810mm Hot Rolling Line in Tang Steel Co., Ltd

Relationship between power consumption in certain area and high voltage system of distribution room in 1810mm Hot Rolling Line in Tang Steel Co., Ltd is shown in Table 3.

Table 3 Power consumption area

Equipment/Electric Consumption Area	Distribution Room	Comments
Continuous Caster 1#	Caster 1#~3#	Caster 1#Power Supply
Continuous Caster 2#	Caster 5#~7#	Caster 2#Power Supply
High Speed Shear 1#	Caster 3#	Shear 1# Power Supply
High Speed Shear 2#	Caster 4#	Shear 2# Power Supply
Tunnel Furnace area 1#	Furnace 1#	Furnace 1# Power Supply
Tunnel Furnace area 2#	Furnace 2#	Furnace 2#, Traverse Section, Insulation Section Power Supply
Rotary Phosphorus Removal Machine	1#~4# Motor	Phosphorus Machine Power Supply(enter R1,R2)
Roughing Rolling Mill	Rectifier Transformer	Roller Stator Power Supply
Roughing Rolling Mill	Power Transformer	Roller Rotor Power Supply
Rotary Phosphorus Removal Machine	5#~9# Motor	Phosphorus Machine Power Supply(enter F1~F5)
Laminar Cooling Section	Run-out Auxiliary RT	Laminar Cooling Section Motor Power Supply
High Speed Down Coiler	Coiler/Core Shaft Auxiliary RT	Coiler DC1, DC2 Power Supply

Note that, (1) The kind of steel is SPHC strip with the thinnest being 1.6mm according to the specification, and casting speed is 4.0m/min, when the thickness of plate strip is 70mm. Continuous caster 1# and 2# control the same casting speed under normal production conditions. (2) Continuous caster can decrease the casting speed when the temperature of slab casting tundish too high, but the casting speed should be no less than 3.5 m/min, and the process should last no more than 30min. The casting speed should be no higher than 4.5 m/min when the temperature of molten steel is too low. Normally, casting stable speed is 4.0 m/min. (3) The casting speed of high speed shear is 3-6 m/min. (4) The length of each heating time of casting billet is 8 min. (5) The length of each rolling time of hot rolled strip is 3 min. (6) The length of each colling time of hot rolled strip is 4 min.

Production technological process could be divided into four main areas, i.e. continuous caster, tunnel furnace, rolling mill and down coil. Electric energy consumption values are illustrated in details with example of rolling mill area. Main equipments and their Parameters of Rolling Mill area are shown in Table 4.

Table 4 Main equipment and its Parameters of Rolling Mill Area

Equipment	Motor/KW	Amount
R_1 Run-in Roller	Gear Motor1.8	7
R_1 Run-in Pinch Roll	Gearbox Motor1.8	1
R_1 Run-in Side Guide	AC7.5	1
Edger	AC120	2
R_1 Four High Mill	AC6600	1
R_2 Run-in Roller	Gear Motor 1.6	4
R_2 Run-in Side Guide	AC7.5	1
R_2 Four High Mill	AC6600	1
Intermediate Roll Area	AC2.2	17
Crop Shear Run-in Side Guide	AC4.5	1
Crop Shear	AC100	1
The top Pinch Roll of Phosphorus Machine	Motor Separating Drive 7.5	1
The bottom Pinch Roll of Phosphorus Machine	AC7.5	2
Phosphorus Machine Roller	AC2.2	2
Finishing Rolling Mill F_1~F_4	AC10000	1
Finishing Rolling Mill F_5	AC7500	1
Crossed Roller F_1~F_3	AC45	4
Width Adjustment of Finishing Rolling Mill	AC15	5
Height Adjustment of Finishing Rolling Mill	AC1.5	5
The Looper of Rolling Mill	AC30	2

During the process when hot rolled strip enters rough rolling mill, rotary phosphorus removal machine and then finishingrolling mill, motor runs from stationary operation state to accelerated operation state. Equipment running acceleration curve is illustrated with example of finishing rolling mill in detail. Motor speed increase and decrease characteristic diagram of finishing rolling mill is shown as Fig. 3.

3.2 Prediction Model

Continuous caster 1# and 2# line are producing casting billet in parallel, 1# line billet enters to heat preservation segment through traverse segment, while 2# line billet enters to heat preservation segment directly. High speed down coiler CD1# and CD2# produce hot rolled strip in turns. Steel and iron producing process and its producing time are shown as Fig.4. Here, let t=8 hours. And then, stationary operation state model Ⅰ in 1810mm Hot Rolling Line of Tang Steel Co., Ltd is shown as Fig.5, and accelerated operation state model Ⅱ in 1810mm Hot Rolling Line of Tang Steel Co., Ltd is shown as Fig.6.

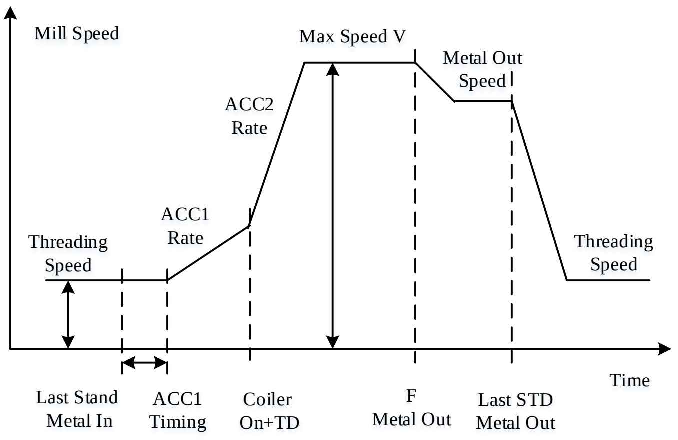


Fig.3 Motor Speed Increase and Decrease Characteristic Diagram of Finishing Rolling Mill

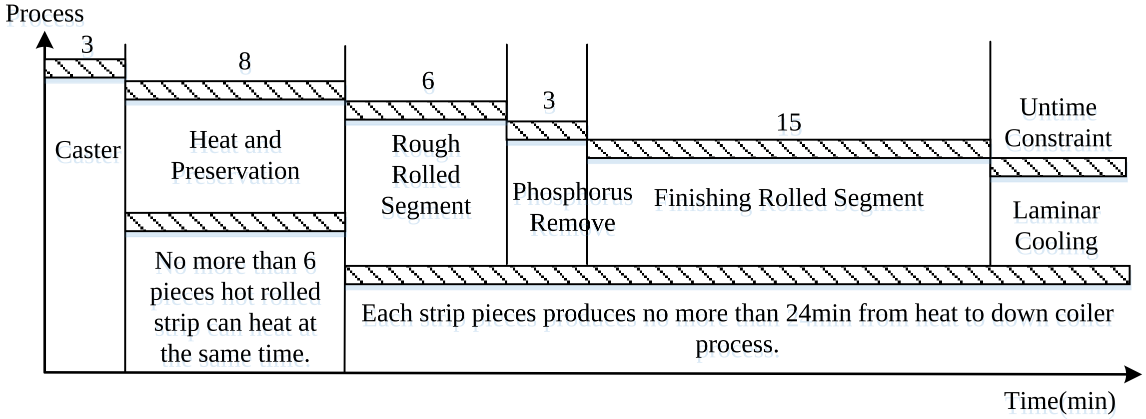


Fig.4 Steel and Iron Producing Process and Its Producing Time

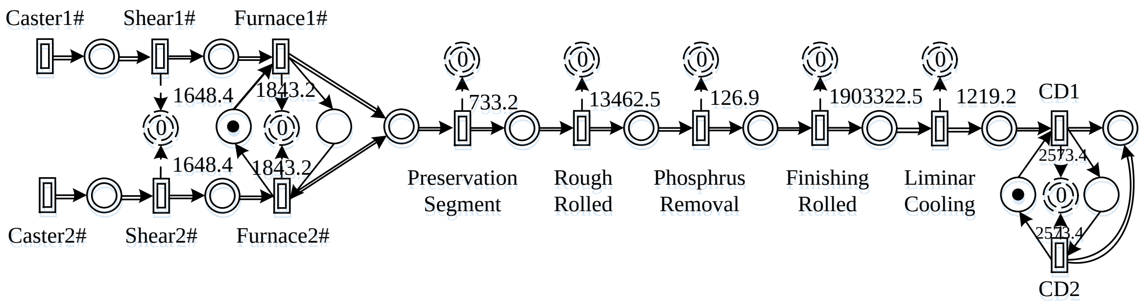


Fig.5 Stationary Operation State Model Ⅰ in 1810mm Hot Rolling Line of Tang Steel Co., Ltd

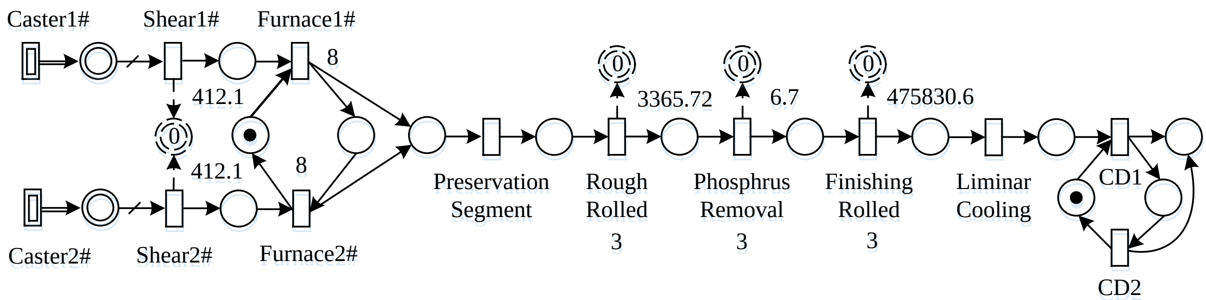


Fig.6 Accelerated Operation State ModelⅡin 1810mm Hot Rolling Line of Tang Steel Co., Ltd

3.3 Power Consumption Calculation

Power consumption E of 1810mm Hot Rolling Line of Tang Steel Co., Ltd is equal to the sum of the power consumption E1 in model Ⅰ and E2 in model Ⅱ in 8 hours. Here, in model Ⅰ, given rough rolled segment as an example, Post=PostR1+PostR2, where, according to Table 4, PostR1= 1.8×7＋1.8＋7.5＋120＋6600=6741.9kwh, and PostR2=1.6×4＋7.5＋6600＋2.2＋4.5＋100=6720.6kwh, hence Post=13462.5, E1=1.54×107kw. In model Ⅱ, set caster speed is 4.0 m/min, length of billet is 24m, and each tunnel furnace can heat 3 pieces billet at the same time. According to figure 3, equivalent accelerated electric consumption is one quarter of stationary's in model Ⅰ, and its producing process time follows that in figure 4. Given those assumptions, accelerated electric consumption within 35min a cycle is 1.44×106kwh, and E2 =1.87×107kwh. Total electric energy consumption E= E1＋E2=3.41×107kwh.

4. Conclusion

In recent years surplus production is a critical issue in steel and iron industry, therefore, enterprises electric power-saving is an urgent problems to be solved. This paper calculates electric power consumption based on rated power of motor in the production equipment, and prove the results in 1810mm hot rolling line of Tang Steel Co., Ltd. Results of this study provide a theoretical basis for steel and iron enterprises delicacy management.

Based on our results, enterprises can take measures below to save electric power engery. (1) increase transmission efficiency of electric power supply network; (2) use frequency control equipment, for example, high speed shear; (3), the optimize production planning, which can significantly increase enterprises energy-saving, because steel production process is an advanced dispatch problem (4) use Internet and Information Technology to energy-saving; (5) apply delicacy management.

The main future work on steel and iron enterprises energy-saving are : (1) research o advanced dispatching method based on energy efficiency assessment index or key performance indicator; (2) using data mining to analysis the potential of energy saving based on materials and energy consumption in production chart process.

Acknowledgements

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