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Reconfigurable manufacturing system research based on water rank model

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ABSTRACT

Aiming at the general limitation of the existing model, the research introduces water rank model to reconfigurable manufacturing systems (RMS), and analyzes and improves the properties of water rank in the research process which combined process control and RMS theory. The research also improves model for reconfigurable system model of the speed change box shell body line and simulated the reconfigurable process of shell line. The result shows that the model can be recognized as instructions and borrowed ideas of production line reconfiguration, and offers an effective organization and control method.

KEYWORDS

RMS model; Water rank model; Reconfigurable manufacturing system.

INTRODUCTION

RMS, Reconfigurable Manufacturing System,is a kind of manufacturing philosophy to guide and manage the reconstitution of the manufacturing system, which offer a comprehensive and systematic view toward the dynamic changes of the manufacturing system. In consideration of the complexity of RMS and the inner requirment that the exsisting manufaturing system need reconstitution under the fast changing market, an appropriate model is needed to describe the system in order to consummate RMS better into a optimal status. The modling of exsisting RMS mainly concentrate on the Petri－Net and Queueing Networks in the areas of which large numbers of research results have achieved. Cai Zongyan comes up with a model, TRPN, Timed Reconfigurable Petri－Net, targeted at RMS, and two reconstitution algorithm in two cases based on the modle; Park adopts Petri－Net as the logic controller of the manufacturing unit of RMS to modle; Sheng Bohao applies Queueing Networks to establish a modle of RMS, and studies the optimal configuration of the buffer size as well as the optimal strategy of workpiece transporting during reconstituition. However, Petri－Net has a low process capacity in complicated manufacturing system, and Queueing Networks has to increase some strict conditions when applied in manufacturing system, which, to some extent, imposes restrictions on the its further development and application of the modling of RMS.

Compared with the above-metioned methods of modeling, the Hydrodynamic Model, HDM, being used to decribe RMS has obvious advantages in that HDM has similar characteristics with RMS, and can be combined with control theory to establish transfer function to describe the system in a precise way. The combination of HDM (water rank model) and the exsisting modeling method can get rid of the the limitations of the past modeling methods. The water rank model is initially proposed by Korea of Michigan university who makes assumption of the manufaturing system, which is still in the preliminary stage. And the studies of water rank model at home mostly focus on the control theory. Therefore, the study of water rank model has a profound practical significance and academic value.

The paper, firstly, establishes a comparatively smaller simple water rank model whose production and manufacturing function can change with the changes of time. And several other water tank models adapted to different environment can be summarized on the base of the above-metioned model. Furthermore, the reconfigurable process of the manufacturing system is analyzed and described by combining the transformation of speed box shell body line and the appliacation of water rank model. The overall performance after the reconstitution of the system is also measured, which, then, is compared with the old production line. It will provide basis to decide whether the system need reconstituting.

THE ESTABLISHMENT AND IMPROVEMENT OF THE WATER TANK MODEL

The establishment of the water tank model

Figure 1 is the model of a single capacity water tank model and the control unit diagram[6]. And the water flowing in represents the rough material being about to enter the production line, the height of the water in the water tank is marked as H representing the prodution level. And the height of the water is changing with the water velocity or the density of liquid, which represents the continious changes of the amount of the raw material that need to process and the types of processing. In summay it represents the changes of the production level demands caused by the flux of market demands. The volume of the water tank represents the production capacity of the whole manufacturing system or a single production line. To simplify the model, the cross sectional area (CSA) of the water tank is regarded constant. As the result, H can represent the production capacity of the system immediately. And the output of the water tank of the current represents the production processed by the manufactuing system.

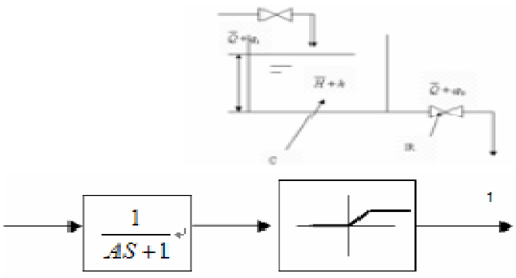


Figure 1 : (a) Single capacity water tank Figure 1 (b) control unit diagram
Figure 1 : Single capacity water tank model

The reconfigurable process of the manufaturing system suggested by the water tank model is shown in Figure 2. The water in the water tank is changed with the material flow. When the water height is lower than the max height of the water tank, the system is conducted normally. When the water height impend over the max height of the water tank, the system is reconsitituted through decision-making. Renconsitution can be achived by changing material flow to reduce the water height in the water tank. Yet it is scarcely adopted in general circumstance considered the max economic benefit. Instead, the system is mainly reconstitued itself to meet the market demands.

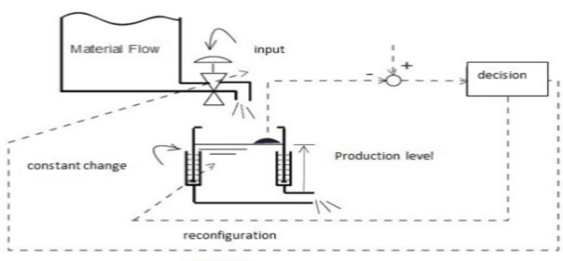


Figure 2 : The reconfigurable process of the manufacturing system

Water tank model meet the production demands in different periods

In order to make the established water tank model close to the real circumstances in production, the model has to be extended. The extended model can be used to satisfy the production demands in different periods, and can be divided into three types: (1) the model to meet the expand production; (2) the model to store and buffer; (3) the model to satisfy multiple demands. The paper mainly aims to study the former two models.

(1) The model to meet the expand production

The model is established a double fluid capacity system as shown in Figure 3, of which Qv_0 is for the input of the water tank 1, Qv_1 the output of the tank1 and the input of tank2, Qv_2 the output of tank 2, H_1 the liquid height of tank1, A_1 the CSA of tank1, H_2 the liquid height of tank2, A_2 the CSA of tank2, RS_1 the hydraulic pressure of tank1, RS_2 the hydraulic pressure of tank2.

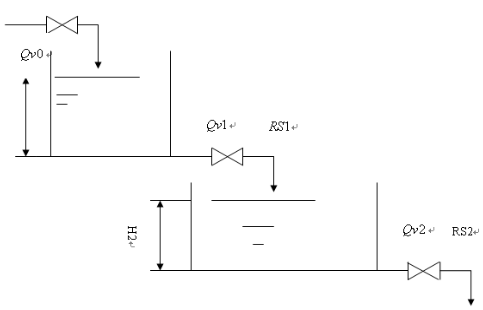


Figure 3 : The model to meet expanded production

According to the balance relation of material, a mathematical model is established:
The dynamic equilibrium of tank 1 is as follows:

$$A_1\frac{dH_1}{dt} = Qv_0 - Qv_1 \quad \textbf{(1)}$$

The dynamic equilibrium of tank 2 is as follows:

$$A_2\frac{dH_2}{dt} = Qv_1 - Qv_2 \quad \textbf{(2)}$$

（1） ＋ （2）

$$Qv_1 - Qv_2 = A_1\frac{dH_1}{dt} + A_2\frac{dH_2}{dt} \quad \textbf{(3)}$$

When the variation of Qv_1、Qv_2 is quite tiny, the relationship of the output of water and the liquid level can be approximately like this:

$$Qv_1 = \frac{H_1}{RS_1} \quad \textbf{(4)}$$

$$Qv_2 = \frac{H_2}{RS_2} \quad \textbf{(5)}$$

Then (4) and (5) are put into (2), and H is differential

$$\frac{dH_1}{dH_2} = RS_1 \times A_2\frac{d^2H_2}{dt^2} + \frac{RS_1}{RS_2}\times\frac{dH_2}{dt} \quad \textbf{(6)}$$

Then (5) and (6) are put into (3)

$$A_1A_2RS_1RS_2\frac{d^2H_2}{dt^2} + (A_1RS_1 + A_2RS_2)\frac{dH^2}{dt} + H_2 = RS_2Qv_0 \quad \textbf{(7)}$$

Through Laplace Change the differential equation is transformed into the expression in S region：

$$A_1A_2RS_1RS_2S^2H_2(S) + (A_1RS_1 + A_2RS_2)SH_2(S) + H_2(S) = RS_2Qv_0(S) \quad (8)$$

Then we can calculate the ratio of Qv_0（S） and H_2(S), thus a transfer function in the control model can be established

$$\frac{H_2(S)}{QV_0(S)} = \frac{RS_2}{A_1A_2RS_1RS_2S^2 + (A_1RS_1 + A_2RS_2)S + 1} = \frac{RS_2}{(1+RS_1A_1S)(1+RS_2A_2S)} \quad \textbf{(9)}$$

(2) The model to store and buffer

The model is then corresponding to asingle input parallel system as shown in Figure 4. The curent is injected into the tank 2 through the valve. In a stable status, both the input and output flowrateare $\overline{Q}$, yet the flow rate between the two vessels are zero. Both the height of vessel 1 and vessel 2 are $\overline{H}$. When t=0, the input flow rate turns from $\overline{Q}$ into $\overline{Q}$ +q, of which q represents the tiny change of input flow rate.

Take qas the input, h_2 the output, the transfer function can be shown as follow:

$$\frac{H_2(s)}{Q(s)} = \frac{R_2(R_1C_1s+1)}{R_1C_1R_2C_2s^2+(R_1C_1+R_2C_2+R_2C_1)s+1}$$

Take q as the input, $q_2$as the output, the transfer function can be shown as follow:

$$\frac{Q_2(s)}{Q(s)} = \frac{R_1C_1s+1}{R_1C_1R_2C_2s^2+(R_1C_1+R_2C_2+R_2C_1)s+1}$$

Take q as the input, $h_1$the output, the transfer function can be shown as follow:

$$\frac{H_1(s)}{Q(s)} = \frac{R_2}{R_1C_1R_2C_2s^2+(R_1C_1+R_2C_2+R_2C_1)s+1}$$

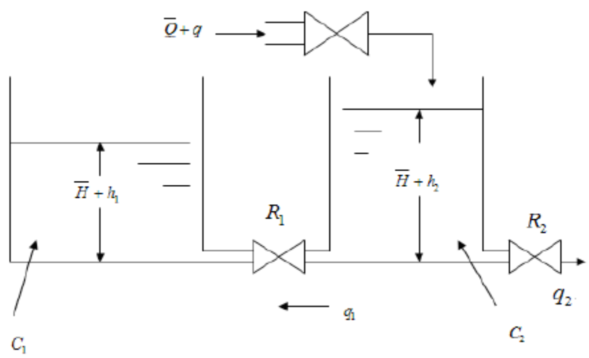


Figure 4 : The model to store and buffer

SOME EXAMPLES OF THE APPLICATION OF WATER TANK MODEL

The above-metioned water tank model can be used to establish a model for a speed change box shell body line. Changing the control stratedy represented by the water tank to meet the production in different period to analyze the reconfigurable process of the manufaturing system as well as the response time, production level, the site plane layout, and the gathering and distribution and changes in other aspects caused by the changes of control stratedy, which, thereby, provide descion –making basis for the manufactuing system of speed change box shell body line, a referecne to the reconstitutin of other manufacturing systems too.

The site data statistics of some speed change box factory

According to the site observation, the production data of the shell boby line is recorded. And the water tank model is used to establish model to simulate and analyze. As playing the most obvious bridging roel in the shell body line, the operation 2 is taken as the main study subject. Operation 2 constitutes a machining center of six NA－60HB, a machining center of one VS500 and a machining centere of three NCV102BA. Through the analysis of the historical records, the reconstitution of speed change box shell body line include following stages:

Stage1 (single type production on single line):

The demand of Type A product in shell body market is 4900 pieces per year. The Worker A operates three machining center, and spends averagely 4-5 min on each piece. The processing time of the machine on each piece is 45 min with each machine processing a piece independly. There is no influnce on each machine. When the process is finished, 4-5 pieces as a set is transferred into the next cleaning process.

When the demand of Type A product in shell body market turns into 9000 pieces per year, three machining center are added after reconstitution. Worker A operates six machining center at the primary stage. In the middle term, Worker B is added to operate the newly added three machines

When the demand of Type A product in shell body market turns into 15000 pieces per year, the processing time of a machine center of 45min is seperated into three manufacturing processes of 7.5 min and one processe of 22.5 min on the principle of seperating processes in the combination of the real site circumstance without any increase of machining center. The three manufacturing processes of 7.5 min are carried out by the primary three machining center, the processe of 22.5 min by the newly added machining center.

Stage 2 (multiple types with a small scale production)

When the demand of Type A product in shell body market drops into 5500 pieces per year, Type B 5000 pieces per year, three NA－60HB machining center are added. Worker A is resposible for the production of A, worker B for B. When the production amount of B is comparatively small, Worker B is going to help Worker A with the production of A.

Stage 3(multiple types with a large scale production)

When the demand of Type A product in shell body market rises into 7000 pieces per year, Type B 10000 pieces per year, one VS500 machining center and three NCV102BA machining center are added. And Worker C and Worker D are added, of which Worker C is responsibel for the operation of one VS500 center and one NCV102BA center, Worker D for the other two NCV102BA center. Thereof, the operation time of each piece the worker spend is averagely 1-2 min. The average operation time of each piece on NA－60HB is 25 min, the time of per piece on VS500, NCV102BA is 5min.
The shell body line plane layout after the reconstitution above-metioned is shown as Figure 5.

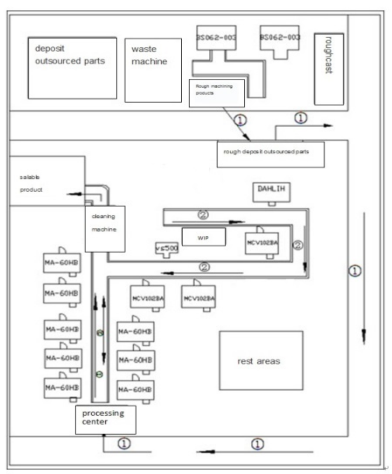
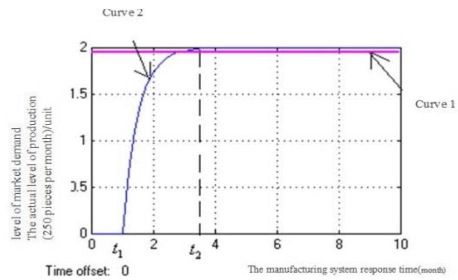


Figure 5 : Shell body line plane layout after the reconstitution

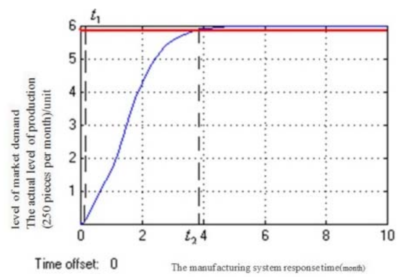
The simulation analysis of shell body line after reconstitution

(1)The first stage simulation

The stage is the transitional stage from “only one product with a small production scale” to “only one product with an enlarged produciton”. In this stage the shell body line just produce Type A, the production amount transit from 5000 pieces per year to 10000 pieces per year. At the first the production line has three same machines, each of which need 45 min to finish a whole shell body that is completed on one mahcine. With the changes of market demand, the prodution amount need to enlarge. Then 3 machinesequiped with modularization function are added which can be used to produce other types of production after adjustment. Then the initial shell body line is simplified as the water tank model with single line and single type in a small scale production. And the reconfigurable model is represented by single input parallel water tank model. According to the interaction effect of the water tank model, the production line can be adjusted to connect in series. Take an example, we can make the three newly added machine do part of the work, and the other three do the rest of it, which can further improve the production. The Matlab is adopted to simulate the shell body production levels before and after the reconstitution, which is shown as Figure 6.



Before reconstitutin



After reconstitution

Figure 6 : The simulation of the shell body line production level before and after the reconstitution in stage 1

(2) The second stage simulation

Due to the changes of the market demand, the speed change box requires to produce two shell bodies of A and B, which need the reconstitution of the whole production line. And the three newly introduced machine are equiped with the group functions in a modularized way, which can be used to produce A and B. Therefore, the production line can be adjusted to meet the market demand. The single line produciton line is transformed into double parallel production line. And the line1 is simply used to produce A in that B is new products with a quiet low demand. Line 2 can produce both A and B.

And the amount of A and B hinges on the production demand, which can be controled by the gain factor K calculated by the transfer function in the water tank model. The water tank model to satisfy multiple types with a small scale prodution can be represented by the model shown in Figure 5, the simulation of its production capacity is shown in Figure 7.

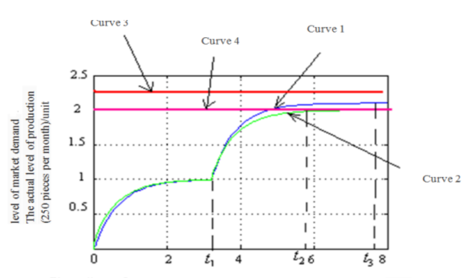


Figure 7 : The simulation diagram of the manufaturing system with mutiple types in a small scale productio

In Figure 7, curve 1 represents the changes of the real produciton level of the system about A, curve 2 the level of the system about B. The curve 3 represents the demand of A in market is 5,500 pieces per year, curve 4 the demand of B in market 5,000 pieces per year. Due to the similarities of the demands of A and B in market, the change of curve 1 and curve 2 is almost the same. In this stage, only

Worker A operates both A and B. With the continious improvement of the system production level, the rough material for processing accumulate more and more. Therefore, when t=3.2, the vacancy rate of Worker A is quite low, which is not reasonable from the view ofergonomics. Then the production level of the system is hard to improve any more. At this moment, the system have a comparatively average distribution of the two production line because the adapation of the system to the market demand is an evolutionary process. After the moment, the system incline to the production of A because the demand of A is slightly higher than B in the market. So the slope ofcurve1 is slightly larger than that of curve 2. And the system is added a new Worker B. Worker A operats the three machining centers in line A, and Worker B the three machining centers in line B. Andone of the maching center in line B will produce A in accordance of the demands. When the system responding time reaches 5.8, the real produciton level of B in the system almost meets the demand of B in the market, which is 500 pieces per month. When thesystem responding time reaches 7.6,the real produciton level of A in the system almost meets the demand of A in the market, which is 550 pieces per month. The total responding time of the system to B is 5.8 months, to A is 7.6 months. Taking a view of the plane layout of the system, the reconfigurable production line is distributed in parallel, which is in facor of the interaction between Worker A and Worker B,and also provides convinient conditons for the later reconstitution. When the control gain parameter is different, the simulation of the produciton capacity of shell body line is shown as Figure 8.

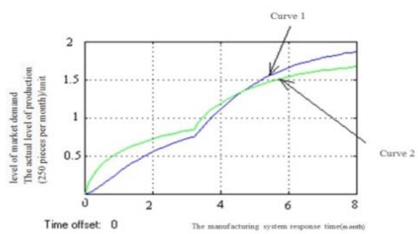


Figure 8 : The simulation of the produciton capacity of shell body line under different control gain parameter

(3) The third stage simulation

The production line after the transformation in the second stage can produce A as well as B. But the max production capacity of the two line is to produce A only of 10,000 piece per year, or only B of 5,000 piece per year. With the increasing demand of the market, the demand for A and B is also constantly improving. The exsiting production cannot meet the market demand any more. Of course, increasing the number of the machines can also improve the production capacity of the system. But it will pay a high price for the reconstitution. Therefore, extracting the four processing steps shared by A and B, each step 5 min, from the procedures of the shell body processing, which can improve the production capacity tremendously. And the first six machining center deal with the primary processing steps of 20 min of A or B.

When the market production level has a further improvement, another two machining center can be added which not only help the production of A or B but also the trial-manufacture of C or D.

The corresponding shell body production capacity represented by the water tank model is shown in Figure 9

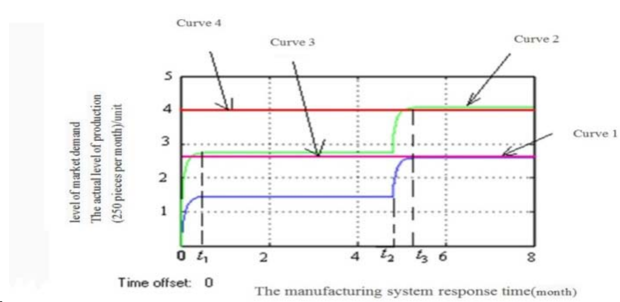


Figure 9 : The simulation diagram of manufaturing system with mutiple types in large scale

The curve 1 represents the changes of the real produciton level of the system about A, curve 2 the level of the system about B. The curve 3 represents the demand of A in market is 7,000 pieces per year, curve 4 the demand of B in market 10,000 pieces per year. As there is little adjustment of the old production line with four new mahcining center added, the responding of the system is vey quick. As shown in Figure 10, when the system corresponding time reaches 0.6, the real produciton level of the system about B has a reached 650 pieces per month, the level of the system about A 350 pieces per month. Then the diagram of the reconfigurable process of the whole system is shown as Figure 10.

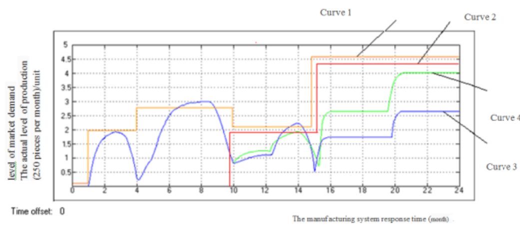


Figure 10 : The simulation diagram of the reconstitution of the whole system

Through the modeling of the water tank, a correspoding transfer function in the control system is established so as to simulate the system to judge whether the system is stable, and the system can be amended in no time according to the simulation results to achieve the optimal reconstitution effect. And in accordance of the water tank model deduced from the third stage, many characteristics of the reconfigurable manufacturing system have been found in it. Therefore, a reconfigurable water tank model is proposed on the basis of the switch of models and complicated multiple model systems.

CONCLUSION

The paper adopts the water tank model in the control engineering theory into the modeling of the reconfigurable manufacturing system, and summaries the former experience to further complete water tank model, establishing a whole water tank model, adopting water tank model into the reconstitution of the speed change box shell body line. The results of the simulation show that through the system model built by the water tank model, further experiment and simulation, the most suitable system can be found, which then is used to make the final decision for the reconstitution.

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