A STUDY OF SYSTEM BALANCE AND CYCLE OPTIMIZATION FOR MULTI-OPERATIONAL EQUIPMENT AND ITS IMPLEMENTATION

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Abstract: This paper introduces one-piece flow production concept and other related theories and methods to improve the balance of multi-operation mechanical system and optimize the operation cycle. An example of full-automatic crimping machine will be exemplified to prove the rationality and feasibility of this study on the last section of this paper.

Key words: one-piece flow (OPF) production; system balance; operation cycle; optimization.

1. INTRODUCTION

Equipment manufacture is a fundamental industry that has a great influence on the Comprehensive National Power. With the emergence of mechanical automation, automobile, light industry etc, the need of putting more emphasis on innovative and fast design as well as rapid manufacture is becoming more and more important for enterprises in the sharply changing market. Moreover, how to reduce product life cycle, find the solution to balance the multi-operational mechanical system and finally develop the potential capacity, attracts more and more focus at home and abroad.

To improve and strengthen the balance of multi-operational mechanical system and optimize the operation cycle, this paper introduces the theory of one-piece flow production into these systems to find out the bottle-neck working procedure and lower capacity resources whose mechanical structure

Please use the following format when citing this chapter:
You, Huan, Lu, Lixin, Li, Limin, 2006, in International Federation for Information Processing (IFIP), Volume 207, Knowledge Enterprise: Intelligent Strategies In Product Design, Manufacturing, and Management, eds. K. Wang, Kovacs G., Wozny M., Fang M., (Boston: Springer), pp. 237-243.

can be re-designed to coordinate the overall performances of the components. After analyzed and simulated by virtual assembly, new mechanical structure of these resources can be obtained, which can largely speed up the production efficiency. During this process, IE (Industry Engineering) related technique and methods will be used. An example of full-automatic crimping machine cooperatively developed by Shanghai Feilo Co., Ltd and Shanghai University will be exemplified to prove the rationality of this method.

2. SYSTEM BALANCE & OPERATION CYCLE

2.1 One-piece Flow Production Theory

One-piece flow (OPF) production is a market-oriented just-in-time (JIT) production system that strives to fulfill the requirements of total quality management (TQM), reduce product changeover time, increase productivity, reduce work-in-process inventory, and eliminate all sources of waste. Initially, the concept of one-piece flow production is closely related with the character of "one piece", which means collocating the working condition, workers, equipment to make sure that only one product stays at each workstation for the cycle time and none existence of buffers for semi-finished products. In this paper, one-piece flow production is extended into the multi-operational mechanical system, which means that the quantity of WIP (work in process) does not exceed the precedence process at any time between two neighboring processes, and that is a non-stop, non-exceed and non-lag process in the movement state. The production in each component carries on almost synchronously, making the WIP to be produced and passed on in a single piece. Once the product has been manufactured completely in one process, it will be put to next process immediately. The OPF production system is a hybrid of the best of all the traditional production systems that insists on waste reduction as the base for improvement.

2.2 System balance

Based on the theory of OPF production, the system balance requires coordinating the overall arrangement and adjusting the operation cycle that can make each component busy at its working period to make good use of its capacity.

Manufacturing a product on the multi-operational equipments requires partitioning the total amount of work into a set of elementary operation named task. Due to technological and organizational conditions, precedence constraints between the tasks have to be observed. If without the concept of system balance, i.e. all components (stations) operate at an individual speed, workpiece may have to wait before it can enter the next process and/or components may get idle when they have to wait for the next workpiece. Under the aforementioned restriction and difficulties, the system balance can be defined as making it easier to carry out the OPF production on the spot and to maximize the operation capacity that is a must to improve the working efficiency and raise the economic performance. The system balance rate can be assessed by the following formula:

$$\eta = \Sigma t/(s*C.T)*100\% \qquad (1)$$

In the Eq. (1), η denotes the system balance rate, S denotes number of components, Σt denotes overall processing time for one production, Cycle Time (C.T.) denotes Pitch Time that equals 3600/Q, and Q denotes the yield per hour.

2.3 Operation Cycle

The balance of production line depends on making each component's cycle time carry on simultaneously. So the time for each qualified output of each procedure can be defined as operation cycle, which can be obtained by the following formula:

$$C = T/R \qquad (2)$$

In the Eq. (2), C denotes operation cycle, T denotes efficient work time, and R denotes number of qualified output.

The efficient work time is the time actually applied into practical manufacture, which can be divided into two parts:

Basic working time, which is the actual time needed for accomplishing the necessary operations, i.e. manufacturing time.

Assistant working time, which is the time left for various assistant operations. These operations ensure the accomplishment of the basic operations.

From the Eq (2), we can know that the system balance relies on the efficient work time. Meanwhile, operation cycle time can be adjusted by the output produced in the efficient work time. So we can enhance the capability of mechanical systems by optimizing the efficient work time and the proportion of its sub-sections.

3. OPTIMIZATION AND EVALUATION

3.1 Optimization

Time-efficiency model is a commonly used model during improvement and optimization of mechanical and electronic products, of which the system balance and cycle optimization can be truly realized. The proposed model is given below:

$$\text{Time}=\sum_{i=1}^{n} k_i T_i c_i^{-\lambda_i}$$

$$\begin{cases} 0 < k_i \le 1; \\ c_i > 1; \\ \lambda_i = \begin{cases} 0(\textit{improved}) \\ 1(\textit{unimproved}) \end{cases} \end{cases} \quad (3)$$

In the Eq. (3), n denotes the number of components, Time denotes overall processing time for one production, T_i denotes processing time of each component with maximum capability, k_i denotes regulating factor for each component to get overall coordination, λ_i denotes improving factor for each component, and c_i denotes efficiency factor for each component after optimization.

There are two ways to realize the goal of optimization: 1) Improve the cooperation among each component on the basis of original system to realize optimal harmonicity, which is mainly to coordinate the value of k_i 2) Improve the overall efficiency (k_i) by restructuring each component (c_i). During re-designing, k_i and c_i are interactive and inter-restrict for finally optimization of the overall equipment.

Obviously, the first way just optimizes the original operation cycle, or only improves the processing ability instead of the original structure. Although it has some limitations, it is still useful in some simple cases. The second way is suitable for improving the system structure, based on which the optimization is carried on in this paper, i.e. finding out and increasing the efficiency of bottle-neck working procedure and other resources (with the lowest capacity) to improve the production ability of the whole system.

3.2 Evaluation

Certain assessment should be performed after optimization. By using the world-top analysis software of CAD and CAE, the whole structure will be improved and developed coordinately during which the detected interference and unreasonable structure will be modified and remodeled for virtual assemble and further assessment, accordingly, the efficiency of whole system can be evaluated by simulation.

4. CASE STUDY

With the fast development of electronic products and emerging application industry, especially automobile industry and consumer electronics, the need of wire harness is increasing dramatically. However, with the demand of high productivity, the problem of low efficiency is emerging.

Following the above concepts and methods, the optimization is carried out over structural improvement of the multi-operation equipment to enhance its efficiency and its market competitive ability

4.1 Flow Chart of Original System

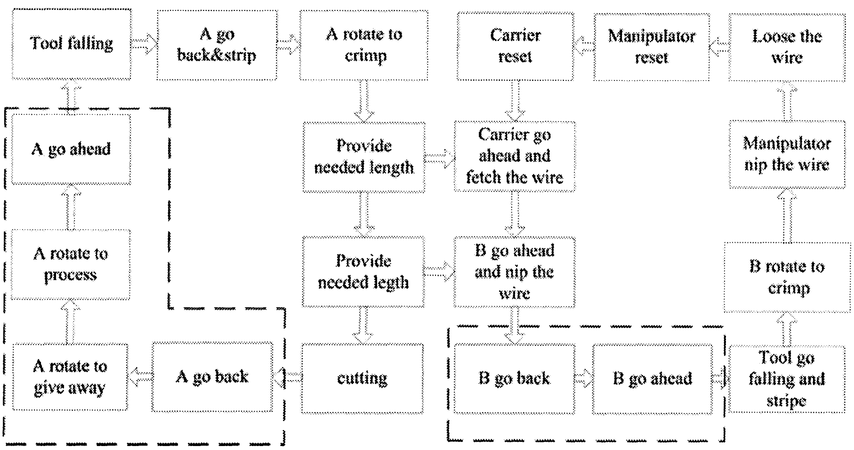

Figure 1. Flow Chart of Original System

As shown in figure 1, the system consists of eight main mechanisms: Front Wire neaten mechanism、Front Wire transmitting mechanism、Front Crimping mechanism 、 Tool Rest mechanism 、 Back Stripping mechanism、Back Crimping mechanism、Back Wire-receiving mechanism and belt mechanism. The principle of this full-automatic crimping machine is as follows: wire-neaten mechanism strains winding wire straight, which then sent to tool rest mechanism for stripping. After stripped, it is time for front crimping mechanism to crimp one end of the wire, while back crimping mechanism nips the wire to wait for its being cut off and rotates to have the other end crimped in the back crimping mechanism. Finally belt mechanism withdraws the finished wire.

Tool is a bottle-neck resource which should finish two tasks as cutting and stripping in original system. As repeatedly used in both ends A and B, especially when finishing crimping one end A and sending the wire to the other part for operation, according to the technical flow, the tool will be both needed in two ends A and B for consequent process. Thus unnecessary time results from the conflict using of tool resource because end A should give away during the operation process of end B and wait until B finishes.

4.2 Improving Scheme

According to the methods put forward in 3.1, we will innovatively substitute three tools for the original one tool in Tool Rest mechanism, which enables the operation of stripping and cutting finish simultaneously. It will alleviate the burden of bottle-neck resource and avoid the unnecessary time of giving away by rotating and waiting. Such an improvement optimizes each component's cooperation, accomplish parallel process and accelerate operation cycle so as to reach one-piece flow production and high efficiency. Two mechanisms are compared in Fig 2

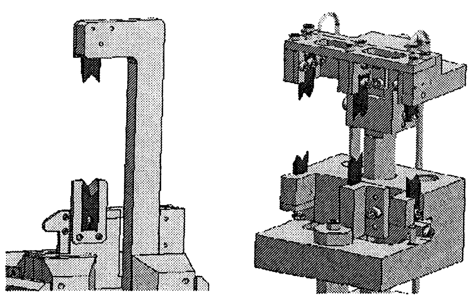

Figure 2. Comparison of the original mechanism with the new one

4.3 Simulation and Assessment

After the initially modeling, dimensions and parameters of each component, the virtual model and assembly will be established by powerful UGNX software for further assessment of collision, interference, etc. The design process will be repeated when meeting something unreasonable during evaluation. According to the Eq.(3), the optimal value of time for the improved model is 0.931s instead of 1.185s of the original one, or an increase of 31%. As to the Eq.(1) and Eq.(2), the optimal system balance rate is 80% instead of 67% of the original one, or an increase of 13%, which totally realized the original intention to redesign and optimization.

5. CONCLUSION

The related technique and methods of IE (Industry Engineering) is very important to reduce consumption and improve productivity. It will play a leading role once carried out in practical production. This paper introduces the theory of one-piece flow production into mechanical systems to find out the bottle-neck working procedure and related resources of low capacity. By re-building the mechanical structure of the bottle-neck resources, constructing the model of time-efficient to evaluate and using UG software to simulate, the system balance and cycle optimization of the machine can be optimized.

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