

Simulation of Mass Customization Oriented Manual Handling System Based on Kcal/ERGO and Ergonomics

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Abstract—Aiming at the manual handling in the mass customization production processes of an automobile manufacturing company which might cause workers fatigue and occupational injuries, the simulation based on Kcal/ERGO is presented in view of Ergonomics. By using ERGO, a Metabolic Rate Prediction Model, and the Kcal Prediction Model, the overall process and system design are presented, and various parts of this production process system design are described in detail. This design directly reflects workers' energy consumption in the procedure and process of work, which can judge whether the process fall within the scope of workers to make production environment in accordance with ergonomics design and ensure that workers can be in a safe, healthy and comfortable working conditions.

Keywords—mass customization; manual handling; ergonomics; ERGO; kcal prediction model

I. INTRODUCTION

With the development of technology today, industrial automation is gradually prevalent in production. But there are still a lot of manual works in the mass customization (MC) manufacturing lines or processes, especially manual material handling[1]. Mass customization is defined as the use of mass production costs and speed to tailor an arbitrary number of products to a particular customer or market. It combines the advantages of batch and customization of these two production models, and understands and meets the needs of users without sacrificing the economic benefits of the enterprise. In the MC production processes, workers suffer from work-related musculoskeletal disorders(WMSDs)in poor working conditions because of bad ergonomic factors, which seriously affect worker's efficiency and health, including lower back pain, sprains and other occupational diseases, etc. The disorders mainly concentrate on repetitive operations, handling operations and long-term bad posture operations. Studies have shown that WMSDs cause great economic losses every year becoming the second highest occupational disease after occupational mental illness[2-3].

Metabolic energy expenditure is an important indicator of workers' fatigue in manual handling. Workers are prone to fatigue when the energy required for work is higher than the energy capacity of workers. In order to improve work environment, meet needs of ergonomic design and complete prior prevent and mass customization manufacture effectively,

using simulation technology in simulating the actual operation of workers becomes the main mean of research[4-5].

This paper took ERGO in digital manufacturing software IGRIP as the foundation, put forward system design and parameters design based on prediction model of energy consumption, and there was an example of mass customization production processes oriented manual handling system in an automobile manufacturing company which proved the effectiveness of simulation.

II. RESEARCH METHODS

A. ERGO Software

ERGO software is an interactive 3D simulation analysis tool of Ergonomics which is suitable for design of workplace and improvement of work environment as a professional tool for human movement and tasks. Using 3D model can analyze human body quickly and accurately in the process of movements or gestures in ERGO. In addition, results of simulation can be further analyzed by Ergo such as Kcal, NIOSH and so on. Therefore, this paper used Kcal prediction model of energy consumption for simulation analysis[6].

B. Prediction of Metabolic Rates

At present, the quantitative analysis method of work load widely used in the world is the model of prediction of metabolic rates proposed by Garg[7]. It is also the mathematical model of this paper. The prediction model divides the energy consumption into two categories. When the process is decomposed into basic variables, the whole energy consumption can be estimated by summing up two types of energy consumption. The mathematical model of Garg is as follows:

$$\bar{E}_{\text{job}} = \frac{E_{\text{job}}}{T} = \frac{\sum_{i=1}^n E_{\text{task}} + \sum_{j=1}^m E_{\text{pos}} * t_j}{T} \quad (1)$$

$$E_{\text{pos}} = K_{\text{pos}} * BW \quad (2)$$

\bar{E}_{job} =Average energy expenditure rate of the job(Kcal/min)

E_{job} =Total energy expenditure(Kcal/min)

T =Time duration of the job(min)

E_{task} =Energy expenditure of i task(Kcal/min)

E_{pos} =Energy expenditure of j posture(Kcal/min)

t_j =Time duration of j posture(min)

K_{pos} =Coefficient of energy expenditure of j posture

BW =Body weight(kg)

The upper limit of metabolic energy expenditure that Garg proposed can be used to assess whether human body reaches fatigue. The formula follows:

$$E_{upperlim} = 9.7 * ((WB * WB2A) + 0.7 * WB(1 - WB2A)) \quad (3)$$

$$WB2A = T_b / (T_b + T_a) \quad (4)$$

T_a =Time of arms(min) T_b =Time of the body(min)

By comparing average energy consumption and the upper limit of metabolic energy expenditure, the human body is in a state of fatigue if it exceeds the upper limit, otherwise it is in a safe state.

C. Kcal Prediction Model of Energy Consumption

The Kcal model is the implementation of the above mathematical model in ERGO, which visually shows the continuous physiological values of worker's work to determine working strength and to ensure that the intensity is within its limits. Before using the model, the motion sequence is decomposed into sub tasks into the model, and the input parameters are shown in table 1:

TABLE I. INPUT PARAMETERS OF MODEL

Parameters	Details
Body posture	Standing straight, standing bent, sitting
Body action	No action, walk, stoop, squat
Left arm action	No action, hand and arm work, hold, push/pull, lift, horizontal work, lateral work
Right arm action	

III. SIMULATION OF MANUAL HANDLING

A. System Design

The first step is to obtain actual operational data of workers to build the model such as workplace layout, work tools, processes, information of workers and other contents through the investigation. The next step is to design parameters and

relationships of components to simulate analysis. The flow chart of the overall design based on the Kcal/ERGO model is shown in figure 1:

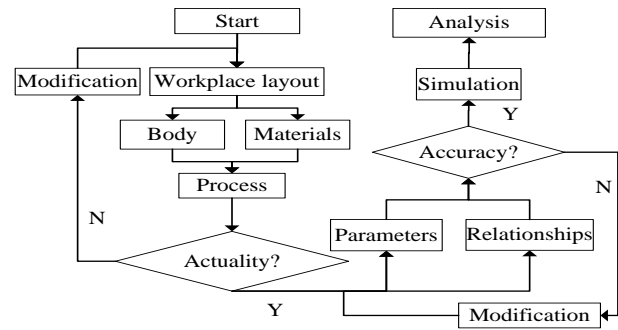


FIGURE I. THE FLOW CHART OF SYSTEM DESIGN

B. Model Building

An automobile manufacturing company has some manual handling operations in the production of welding process such as moving tyres to wheel assembly table, the loading and unloading of the body welding process as well as moving materials to the line. This paper took the operation about the loading and unloading of the body welding process as the object of the study, established simulation model in ERGO, analyzed by using Kcal, and understood risk factors through results of workers' energy consumption. The worker A carried the material B (weight:10kg) from the table to the working table by manual handling. The first step is to establish a body model of worker A, work environment, work path, and a series of specific gestures during the handling process. The human model constructed is a male worker of fiftieth percentile, and the information of the worker is shown in table 2:

TABLE II. BASIC INFORMATION FOR WORKER A

Worker	Sex	Height/cm	Weight/kg
A	male	175.49	77.69

The worker A went to the table from the start point, then grabbed the material B and lifted, moved to the working table, and placed B, finally returned to the end point. The time of lifting and placing were 2s. The simulation diagram is built as shown in figure 2:

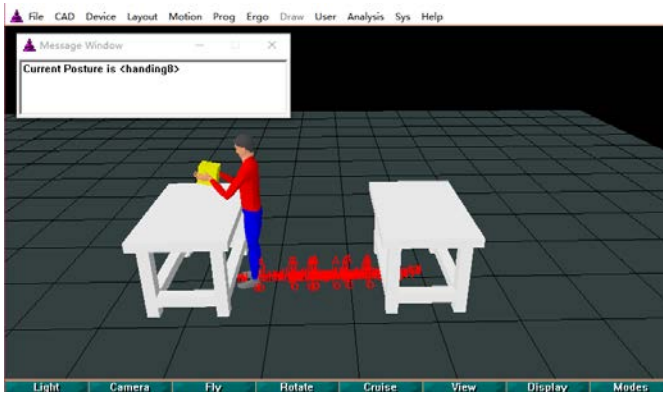


FIGURE II. THE MODEL OF SIMULATION

C. Parameters Design

Designing parameters of the Kcal model needs to enter key actions of the process in turn. Take phase 1 as an example. First, analyze the operational process. A started from the start point to the table where the B was placed at the beginning. This stage was walking without special movements for both arms. Input into the model as shown in figure 3. Then determining key actions, analysis the operation process based on the principle of motion decomposition and process analysis, and design parameters were proposed. There are 8 key actions which were input into the model in turn.

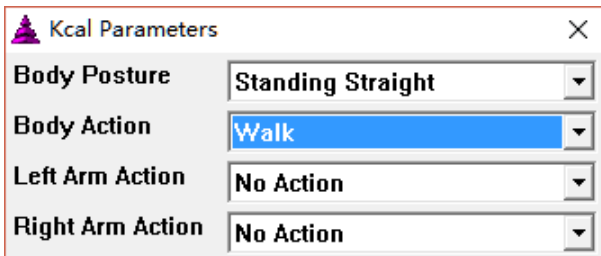


FIGURE III. MODEL PARAMETERS OF KCAL

D. Relationships Design

The relationships design of components is very important in the construction of the whole model. In the process, the seventh gesture marked the beginning, and the worker A began to grab the material item B through the example of phase III. The relationships of components were required at this time including the worker's physical relationship, the dual arm relationship and the head tracking relationship, etc.

The relationship between the body and the right arm was the table where the object B was placed, and the relationship between the left arm and the head was B as shown in Figure 4.

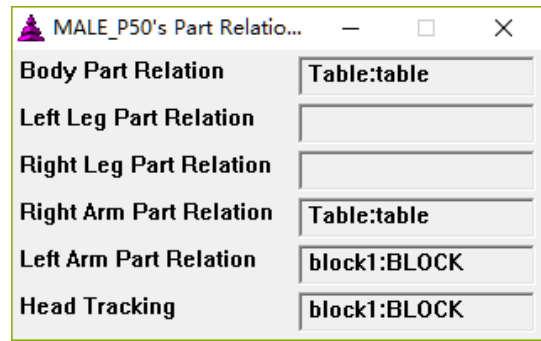


FIGURE IV. THE RELATIONSHIPS OF THE LIFTING PROCESS.

IV. SIMULATION RESULTS

According to the system design and parameters design based on Kcal/Ergo model, setting the corresponding parameters and dynamic simulation, we drew results about the analysis of energy consumption including energy consumption of each sub task and the total. Some of the results are shown in figure 5:

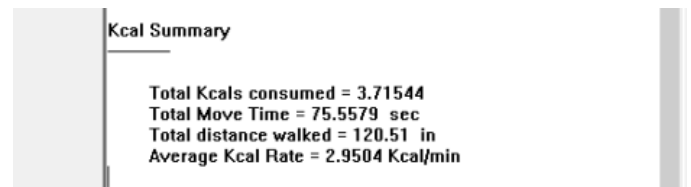


FIGURE V. SIMULATION RESULTS OF KCAL

The worker A's average energy consumption rate is highest in phase III when he lifted the material B, and its value is 4.13072Kcal/min by comparison of results as shown in Table 3. Second is the fourth stage and the value is 3.69156Kcal/min whose total energy consumption is the largest at 41% as shown in Figure 6. In the meantime, the upper limit of metabolic energy expenditure is 9.42 calculated by the formulas (3) and (4). They are safe by comparing the upper limit with the average energy consumption of tasks.

TABLE III. ENERGY ANALYSIS RESULTS

Task	Details	Consumption/Kcal	Time/s	Average energy consumption/Kcal/min
1	Start	0.5846	14.7072	2.3850
2	Lift arms	0.2451	3.5825	2.6346
3	Lift materials	0.2349	3.4120	4.1307
4	Send materials to the working table	1.4846	24.1291	3.6916
5	Lower arms	0.2388	3.4580	2.6248
6	Place materials on the working table	0.2012	3.9393	3.0646
7	Return	0.7263	18.3299	2.3773

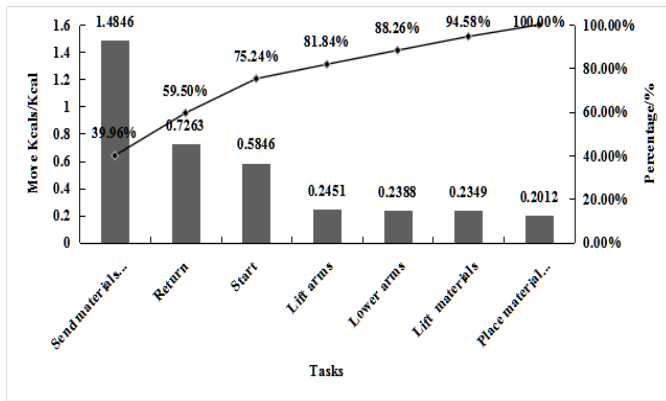


FIGURE VI. THE PARETO OF ENERGY CONSUMPTION

The worker A's energy consumption is at a moderate level, which may lead to fatigue and muscle damage resulting from results of energy consumption. Therefore two stages of consumption can be improved from the point of ergonomics so as to reduce the fatigue of workers and optimize the overall operation processing. It can provide some auxiliary production tools such as conveyor belts, transport vehicles, etc., improve workplace layout to reduce the distance between tables, and arrange the appropriate staff shift rest system, and so on.

V. SUMMARY

1) It is proved that the complete solution of process planning and analysis, operation training and so on can be realized by using simulation software to analyze human body in ERGO before work in order to complete prior prevent and mass customization manufacture effectively. It can not only reduce the actual workstation investment and the cost of simulation, but also provide convenient, accurate calculation and verification analysis to improve the feasibility of design program to ensure the safety of workers by simulation technology.

2) The theoretical analysis and simulation analysis based on Kcal Prediction Model of Energy Consumption were carried out. It was proposed that the system design and detailed parameters design for mass customization production oriented manual handling system in an automobile manufacturing company and realized simulation in the actual case. The result showed the dynamic situation of energy consumption about each movement and the whole process, and finally put forward the reasonable improvement.

3) The values of energy consumption can be used to determine whether the process falls within the scope of workers according to the simulation results of workload to avoid excessive fatigue. It can reflect the modern industry uses the application of simulation software to solve actual problems in manual handling. In the meantime, this method can make the production environment to meet the principle of ergonomic design, prevent and control effectively accidents and physical injuries that workers may suffer from in the process of manual materials handling, and ensure that they are able to work in safe, healthy and comfortable operating conditions. However, it is impossible to add environment and other objective variables to the calculation of energy consumption by using simulation software, which maybe lead to errors. If workers work at high temperatures, the energy consumption varies

considerably. Therefore, it is necessary to make a further revision of the calculation results, which will be more objective and convincing in security assessment.

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