SYSTEM ANALYSIS OF EFFICIENT PRODUCTION PROCESSES FOR PRODUCTIVITY ENHANCEMENT THROUGH PRODUCTIVITY BALANCE IN INJECTION MOULDING PROCESS

R. Usubamatov, S.M. Sapuan, M.M.H.M. Ahmad and N. Ismail
Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor.
E-mail: sapuan@eng.upm.edu.my

ABSTRACT

The purpose of this paper is to present a study of mathematical model of system analysis of efficient production processes. Its objective is to perform productivity balance calculation based on data obtained from injection moulding process. Discussion on system analysis of production processes for productivity enhancement is presented. The definitions of machining time and idle time are given. The importance of coefficient of machine is also discussed. The methodology adopted in the study was to calculate the coefficient of machine of injection moulding process. The productivity balance diagram is presented to illustrate various losses associated with productivity. The productivity balance is developed based on mathematical calculation proposed and various productivity losses were identified. The improvement can be made based on these losses. An investigation was based on data obtained from injection molding machine from a company in Klang Valley. The main findings from this study include the main losses in injection moulding process can be divided among all the losses at the ratios of idle times as 0.45:11.11:0.1:0.06. These losses are $\Delta QI = 0.003$ parts/min, $\Delta QII = 0.0562$ parts/min, $\Delta QIII = 0.0005$ parts/min and $\Delta QIV = 0.0003$ parts/min. It is concluded that engineers have to create new machines with continuous processing without cyclic idle time in order to step up the automation, to solve problem in changing automatic tool, to increase the reliability of the machine, to create real automatic control of manufacturing system, to adapt automatic control of quality of parts and to determine accurate and flexible production system.

Keywords: *Injection Moulding, Production Process, Productivity Balance, Productivity Enhancement, System Analysis*

1. INTRODUCTION

In the modern age, manufacturing industry has to face various challenges in order to stay competitive. The companies can no longer content with their current practices if they are to remain relevant in the market place. Therefore, industrialists require various techniques and approaches in order to increase productivity.

Various studies have been conducted in the past to improve the manufacturing process. Amen [1] carried out the study on the solution quality and computing time requirements of heuristic methods for cost-oriented assembly line balancing. He compared existing and new heuristic methods for solving the cost-oriented assembly line balancing. The new methods 'best change of idle cost' and 'exact solution of sliding problem windows' are recommended to solve the cost-oriented assembly line balancing problem within acceptable computing time.

Carter and Silver [2] stated that the layout of production facilities is an important determinant of the productivity potential of a manufacturing enterprise. They described the methodology for designing approximately minimum cost paced assembly lines under conditions of random task times of off-line repair of incomplete tasks. In order to achieve productivity enhancement in dies and moulds manufacturing, Boujelbene et al. [3] used continuous tool path to achieve the specified dimensional and geometrical accuracy and to improve surface roughness in automotive industry and injection moulding sector.

Elghobary et al. [4] presented a paper on the application of a computerised work sampling technique to a production line of piston ring to increase its productivity by minimising the material waiting time between production stages, and minimising the operators idle time. In their views, the optimum design of productive plants is considered to be one of the basic factors to obtain maximum productivity. Khoshnevis and Wolfe [5] developed a model and a solution method to incorporate the effects of operator learning, retrogression and manufacturing progress function into the aggregate production planning of short-cycle products.

The work of Gaalman et al. [6] is concerned with a simulation study to investigate the possibility of reducing the investment in tools by sharing the tools among the machines by means of an automated tool transporting vehicle. The results of their study indicated that the system can be used with less investment in tools while maintaining a small fraction of machine idle times. Nagarur and Azeem [7] performed a simulation study on impact of commonality and flexibility on manufacturing performance criteria such as makespan, machine utilisation and factor productivity. The case study was analysed using the simulation tool SIMPLE++. From the study, it was found that the makespan decreases, whereas machine utilisation and factor productivity increase by the introduction of commonality to the existing system.

Although various papers have been reviewed on various important issues in manufacturing, none of the above studies have carried out the work on productivity balance in order to achieve efficient production process. The problem in manufacturing industry now is due to lack of research papers that dealt with the use of mathematical model based coefficient of machine and that came up with productivity balance. The purpose of this paper is present a study of mathematical model of system analysis of efficient production processes with the productivity enhancement in mind.

System analysis of production processes presents powerful approach in solving the problem of productivity enhancement and efficiency of complex production processes in order to demonstrate the way in improving the accuracy and quality of manufactured products. Normally the results of the analysis are verified using mathematical approaches. System analysis of production processes is a universal method and can be applied to any kinds of production processes like controlling city bus traffics, controlling airline traffics, food processing and so on. As a case study, in this paper, the productivity improvement is made on injection moulding process in a company located in Klang Valley. The objective of this paper is to perform mathematical calculation of machine productivity for injection moulding process to come up with a productivity balance for the process. The main contribution of this paper is on the development of a productivity balance for injection moulding process and this kind of development can be extended in other domains.

2. MACHINING TIME VERSUS IDLE TIME IN PRODUCTION PROCESSES

Modern production processes are carried out using complex and very expensive equipment like automatic machines and production lines. Industrial managers are looking for ways to use all equipment in full capacity and to obtain maximum productivity and efficiency. In reality, in the field of complex system especially when it involved the exploitation of automatic machines and production lines, these automatic machines and production lines do not operate at their maximum capacity due to many reasons. The time taken (budget time) for the automatic machines to operate can be classified as machining time and idle time. Generally idle time is the time lost because the machines did not produce articles and caused the reduction in factory productivity and in factory incomes [1].

Extensive analysis on established manufacturing processes shows that automatic machines do not work constantly. There are times when the automatic machines do not work and the productivity demonstrated by these machines is inferior to that was calculated in the operating manuals.

A. Cyclic idle time versus out of cycle idle time

The reason for this poor performance can be attributed to two main idle times namely cyclic idle time and out of cycle idle time that contribute to the decrease in productivity of the automatic machines.

Cyclic idle time of automatic machines is due to auxiliary motions like material feed, the transportation of work pieces in the right position, the orientation and clamping of work pieces and moving in and out of the machine heads [2].

Out of cycle idle time for machining process can be attributed to:

- changing, sharpening and setting up of tool
- fixing and maintenance of machines due to mechanical, electrical and electronic problems
- administrative and technical problems due to insufficient work pieces, absence of workers, changing shifts and cleaning of machines
- defect in work pieces and in machined parts
- machine set up due to production of new articles, change in technological mechanisms,
- kinematical set up, control program and change in tooling.

Out of cycle idle time is considered as loss of productivity and can be divided into two parts:

- loss due to technical problems that are connected to machine construction and processing regime. The examples of these include setting up and maintenance of mechanisms, regulating and tuning the tools and the elimination the machining process due to parts that have some defects.
- loss due to organizational, managerial and general technical problems such as insufficient work pieces, disciplinary problems of the workers, parts contain some defects from previous machining process and decreasing of different types of power supply.

3. METHODOLOGY

An investigation was carried out on the injection moulding machine work in Malaysian Auto Product Sdn. Bhd. located in Klang Valley. The research was carried out for mass production of the rubber seal part SL 3035 and all data were recorded according to the proposed methodology. The data was collected by the principal author during his association with the company. The introduction of term coefficients of machine which are obtained from Russian literature [8,9] was the main tool used in this study. Detail explanation on coefficient of machine is given in the following sub-section. The productivity balance is developed based on mathematical calculation proposed and various productivity losses were identified. The improvement can be made based on these losses.

A. Coefficients of machine

All the losses mentioned above can be expressed using coefficients of machine [8,9] and these coefficients are analytically dependent on machine productivity. These coefficients are calculated based on productivity losses of machine due to organisational, managerial and general technical reasons.

These coefficients reveal the proportion of budget time spent on machining, given the availability of work pieces, tools, power, technicians and workers and the proportion of budget time spent on technical maintenance, changing, setting up and tuning of tool mechanisms of the machine.

Available calculation method can be used to characterise the reliability of machine and the stability of technological process. It can be used to characterise which part of budget time is used to carry out works like machining, repairing and tuning, and which part of budget time is spent when the machine is standing idle due to external factors that do not have connections with machining process.

For instance, if the coefficient of machine is given the value of $C = 0.80$, it means that 80% of the budget time is spent on carrying out the real machining work and maintenance and

20% of budget time is spent when the machine is standing idle due to organisational, managerial and general technical reasons. It means that the machine is only using 80% of its potential in such production conditions.

B. System analysis of manufacturing processes

System analysis of manufacturing processes focuses on two aspects:
- to calculate the provision for the increase in the machine productivity in a particular production condition, and
- to decide on the initial date to design a new machine that has a similar technological process with the existing one but at higher technical characteristics.

Analysis of manufacturing processes must begin from:
- the study of technological process production of parts (the study of methods, routes, regimes, accuracy, and other technical requirements to obtain high quality processing of parts).
- the construction of all machines and mechanisms involved in technological process.
- organization of machine use.
- managerial aspects.

The next analysis is on the actual fixing of work to be machined and the records of all machines in use. During the analysis it is necessary to record a budget time spent in machining of parts and time spent in idle conditions due to technical, organisational and managerial problems, methods of repair, quantity of parts produced per shift and the length of each cycle. The length of operation can be determined using mathematical principles. In the records, the information on the time taken for each machining operation and the cause of machine is in idle are recorded, so these records contain all information that are required to characterize machinability of the work piece [10].

The records contain huge amount of information and their development enables the designer to come up with the information on the capacity of machine, the quality of machine, the provision to increase machine productivity, the accuracy of machine to carry out machining process and the reliability of the machine.

The characteristics of the machines can be determined from two types of documents namely:
- the actual machine cyclogram and
- the actual budget time spent.

These information can be used for calculating the following:
- coefficient of machine being used,
- coefficient of machine loading,
- machine productivity losses per part,
- real productivity of the machine,
- provision to increase the productivity of machine.

4. RESULTS

The results of the study are presented as follows:

A. Productivity balance

Calculation of machine productivity can be used to lower the losses of machine productivity. It can be shown in machine productivity balance in Figure 1. In this figure the productivity losses are shown and the losses are due to many factors.

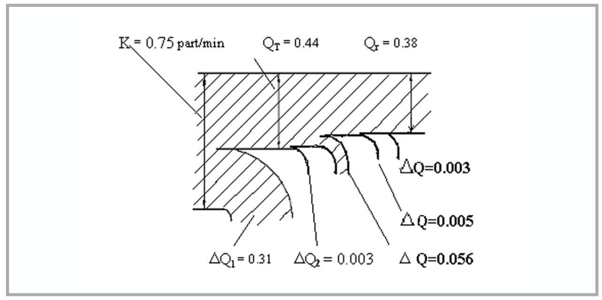

Figure 1: Productivity balance of the injection molding machine

The study of machine productivity in real production environment focuses on two goals
- definition of a productivity reserves and
- definition of initial parameters to design new machines with higher productivity.

The study of machine productivity begins from the study of the technological processes, construction of machines and system of exploitation of machine. Then machine work photography is conducted during 12-18 shifts with all idle times recorded. Similarly, the records of a machine stoppage, quantity of produced articles per shift and cycle time are noted.

All records of the injection molding machine productivity study is developed and presented in the Table 1.

Table 1: Injection molding machine productivity study

Element of budget time spent	% to budget time
Idle time due to tools – I	0.45
Idle time due to equipments – II	11.11
Idle time due to management – III	0.1
Idle time due to defects of production – IV	0.06
Total idle time due to technical reasons Θt	11.62
Total idle time due to managerial reasons Θm	0.1
Total idle time Θi	11.72
Work of injection molding machine Θw	88.28
Budget time of work study Θ	100
Cycle time T = 2.23 min	
Processing (cure) time tm = 1.33 min	
Auxiliary time ta = 0.9 min	

Calculation of the basic parameters of injection molding machine productivity is:

1. Coefficient of injection molding machine use is:
   $\acute{\eta} = 1/(1+\Sigma\Theta i/\Theta w) = 1/(1+11.72/88.28) = 0.882.$

2. Technical coefficient of injection molding machine use is:
   $\acute{\eta}_t = 1/(1+\Sigma\Theta t/\Theta w) = 1/(1+11.62/88.28) = 0.883.$

3. Out of cycle loss is:
   $\Sigma ti = (\Sigma\Theta i/\ \Theta w)\ T = (11.72/88.28)\ 2.23 = 0.29$ min/part.

4. Real productivity is:
   $Qr = (1/[T+\ \Sigma ti\ ]) = (1/[2.23+0.29]) = 0.38$ parts/min.

5. Cyclic productivity is:
   $Q_T = 1/T = 1/2.23 = 0.44$ parts/min.

6. Technological productivity is:
   K = 1/tm =1/1.33 = 0.75 parts/min.

7. Productivity loss due to auxiliary time is:
   $\Delta Qa = K\text{-}Q_T = 0.75\text{-} 0.44 = 0.31$ parts/min.

8. Productivity loss due to technical and managerial reasons is:
   $\Delta Qt, m = Q_T - Qr = 0.44\text{-}0.38\text{=}0.06$ parts/min.

To make the calculation more user friendly, the readers should go through it with reference to Table 1.

These common losses can be divided among all the losses at the ratios shown in Table 1 of idle times as 0.45:11.11:0.1:0.06. Thus:

ΔQI = 0.003 parts/min
ΔQII = 0.0562 parts/min
ΔQIII = 0.0005 parts/min
ΔQIV = 0.0003 parts/min

Graphical presentation of the line productivity losses is shown on the Figure 1 where major losses are due auxiliary time, due to equipments reasons and so on. The figure is actually of the summary of the calculation performed above. It means, if the machine is 100 % efficient, it can produced 0.75 parts per minute. However, due to some losses during the process, it finally can produce only 0.38 parts per minute.

All these losses are the sources of increasing production of the injection moulding machine. Engineers must decide these problems that enable to decrease productivity losses.

5. DISCUSSIONS

Productivity balance of the machine clearly shows what kinds of losses occur in the machine during processing and the percentage of each loss are shown. Productivity balance enables designer to calculate the reasons for which one sector gives low productivity compared to the others.

The machine productivity losses can be considered as dynamic factors in developing the processing technique. In the case study presented above, productivity loss was very obvious. In the system that is fully efficient, the productivity is 0.75 parts per minute. However, due to some losses during the process, it finally can produce only 0.38 parts per minute. This is where the role of manufacturing engineers is very crucial. Engineers have to create new machines with continuous processing without cyclic idle time in order to step up the automation, to solve problem in changing automatic tool, to increase the reliability of the machine, to create real automatic control of manufacturing system, to adapt automatic control of quality of parts and to determine accurate and flexible production system [11].

Manufacturers who are willing to achieve higher productivity but sometimes they made wrong decisions in purchasing new equipment. They do not take full benefit of the existing machines, do not make any improvement in production lines to enhance their technical characteristics, do not make improvement on the management and organisation of production and do not make new investment. It is an easy and not an expensive way to conduct system analysis of manufacturing processes and to enhance productivity of machines, production lines and to improve the accuracy and quality of the products [12,13].

The use of mathematical model in solving some of the manufacturing problems has become a common routine [14]. However, the approach taken in this paper is based on the extended duration of work performed by the principal author in Russia. Since the original work was reported in Russian language, it is very difficult task to present the work in English. This paper is among the initial attempts to convert the idea of the principal author from Russian to English. The new approach presented in this paper can be used wherever suitable particularly by the Malaysian engineers in solving some of their manufacturing problems.

6. CONCLUSION

Malaysian manufacturing industries can carry out system analysis of manufacturing processes in order to solve the manufacturing problems. The proposed system analysis of manufacturing processes is universal and it is possible to apply this system to any kind of technological processes and in this paper, it is applied in injection moulding process for making rubber seal part. The main findings from this study include the main losses in injection moulding process studied can be divided among all the losses at the ratios of idle times as 0.45:11.11:0.1:0.06. These losses are ΔQI = 0.003 parts/min, ΔQII = 0.0562 parts/min, ΔQIII = 0.0005 parts/min and ΔQIV = 0.0003 parts/min.

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PROFILES

R. Usubamatov
Department of Mechanical and Manufacturing Engineering,
Universiti Putra Malaysia,
43400 UPM Serdang, Selangor.

S.M. Sapuan
Department of Mechanical and Manufacturing Engineering,
Universiti Putra Malaysia,
43400 UPM Serdang, Selangor.

M.M.H.M. Ahmad
Department of Mechanical and Manufacturing Engineering,
Universiti Putra Malaysia,
43400 UPM Serdang, Selangor.

N. Ismail
Department of Mechanical and Manufacturing Engineering,
Universiti Putra Malaysia,
43400 UPM Serdang, Selangor.