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Influence of variability of polymer processing on the manufacturing system

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Analysis and modelling

ABSTRACT

Purpose: The aim of the paper is to present the influence of variability of polymer materials processing parameters on the production process. To determine this influence, the queuing theory and system dynamics method have been applied.

Design/methodology/approach: The measurements and control of the time of operation can be performed by means of the traditional methods of statistical control. Full dynamics of the variability phenomenon can be reflected by means of computer simulation.

Findings: The measurements of parameters on the basis of real manufacturing system have been performed. The dependences between the parameters have been determined and several computer simulations have been performed. On the basis of the obtained results the influence of the individual production parameters on the manufacturing system has been determined.

Research limitations/implications: The performed analysis enabled to assume that the highest influence on the manufacturing process and especially on the time of material flow has the time of injection of the polymeric materials. Reductions in utilization tend to have a much larger impact on delay then reduction in variability. However, because capacity is costly, high utilization is usually desirable.

Originality/value: The investigation results can be the basis to develop efficient methods for reduction of variability and hence the methods of production costs reduction. Variability reduction is often the key to achieving high efficiency logistical and manufacturing system.

Keywords: Statistic methods; Engineering polymers; Variability parameters

1. Introduction

The success in the company which uses the polymer material processing depends on many factors. One of them is the applied processing technology. It is the technology which determines the whole manufacturing process. Achievement of the satisfactory results is connected with the definition, measurement and control of the part of the manufacturing system connected with polymer materials processing. The production cycle can be controlled only after determination of the relationships of the cycle with the productivity, production capability, machine utilization factor and the method of controlling the production capacity. The phenomenon of variability of manufacturing processes is also very important to the course of the manufacturing process.

Variability occurs in all processes and is an inevitable phenomenon. As the investigations show, it has the unfavourable effect on the manufacturing process. It generates significant costs connected with improper material use, maintenance of the machine, costs connected with time consumption of the processes. It is therefore necessary to reduce the variability. However, its measurements are not an easy task. Presently the statistic methods of process control are used, yet they do not enable to reflect the whole dynamics of the phenomenon [1]. During the dynamics analysis a useful tool is the computer simulation. The obtained numerical results indicate the characteristic and dynamics of the changes for each parameter of the manufacturing process.

2. Investigation methodology

In the analyzed manufacturing system, the ABS and PP plastics have been processed. As a result of final process the moulded pieces which are the components of the industrial fan have been obtained. The model of the manufacturing process has been developed. The construction of the model was started from the determination of the input parameters for the polymer materials processing and service and output parameters for one link of production line i.e. injection moulding machine. Then, the fundamental values which describe the manufacturing process have been determined [2].

- expected time value for the time of material waiting in the queue for processing CT_q,
- expected time value for processing the material in the workstation CT (i.e. the total of waiting time before the station and plastic processing time on the machine)
- expected material amount value for the material in the queue before the workstation WIP_q,
- expected material amount value for the material processed on the workstation WIP,

The relative machine utilization u has been determined. It amounted on average 70%. The result below 100% shows that the material processing process on the injection moulding machine has a certain steady state. To determine these parameters, Little's law can be applied. These parameters can be described by the equations [3]:

$$u = \frac{r_a}{r_e} = \frac{r_a \cdot t_e}{m} \tag{1}$$

$$CT = CT_q + t_e \tag{2}$$

$$WIP = r_a \times CT \tag{3}$$

$$WIP_q = r_a \times CT_q \tag{4}$$

On the basis of queuing theory, the average waiting time before workstation can be expressed by the dependence [4]:

$$CT_q = \left(\frac{c_a^2 + c_e^2}{2}\right) \cdot t_e \cdot \frac{u^{\sqrt{2\cdot(m+1)}-1}}{m \cdot (1-u)} \tag{5}$$

On the basis of these dependence, CT, WIP i WIP_q can be determined.

For the workstation consisting of m number of the machines with any polymer material processing time distribution, the expected value of the time spent in the workstation:

$$CT \approx \left(\frac{c_a^2 + c_e^2}{2}\right) \cdot t_e \cdot \frac{u^{\sqrt{2\cdot(m+1)}-1}}{m \cdot (1-u)} + t_e \tag{6}$$

czyli

$$WIP = \left[\left(\frac{c_a^2 + c_e^2}{2}\right) \cdot t_e \cdot \frac{u^{\sqrt{2\cdot(m+1)}-1}}{m \cdot (1-u)} + t_e\right] \times r_a \tag{7}$$

with:

u - relative utilization of the injection moulding machine

r_a - frequency of new jobs,

r_e - frequency of completion of the jobs,

m - number of machines in workstation,

c_a^2 - square variability coefficient of new jobs,

c_e^2 - square variability coefficient for effective processing time.

The subject of the detailed studies was the square variability coefficient for effective processing time and its influence on the other values. This coefficient can be expressed by the dependence [6]:

$$c_e^2 = c_0^2 + 2 \cdot A \cdot (1-A) \cdot m_r \cdot \frac{1}{t_0} \tag{8}$$

with:

c_0^2 - natural square variability coefficient

A - machine's availability

$$A = \frac{m_f}{m_f + m_r} \tag{9}$$

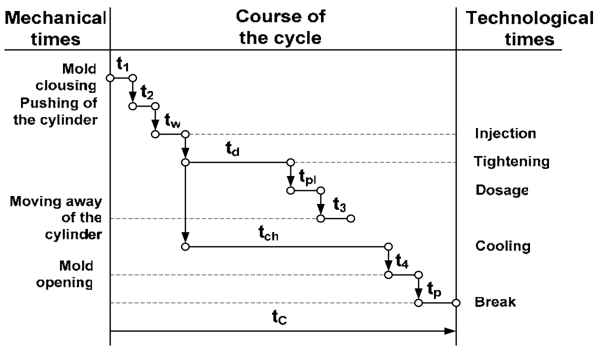
m_f - mean time to failure

m_r - mean time to repair,

t_0 - time of the material processing i.e. injection cycle time

These equation have been verified. The results have been presented in papers [5, 6, 7].

The variable here was a polymer material injection cycle time. These time consists of the injection machine mechanical movements and the technological times, dependent on the process course conditions [8] (fig. 1).



$$t_0 = \underbrace{t_1 + t_2 + t_4}_{\text{mechanical times}} + \underbrace{t_w + t_{ch} + t_p}_{\text{technological times}}$$

Fig. 1. Diagram for the standard cycle time

Very often, in order to increase the production capacity, the injection cycle time is shortened. The measured cycle number during thin-walled elements amounted on average 25 cycles/min. The strongest influence on the cycle time have: cooling time, mechanical times and downtimes. After the determination of each time the injection process optimization is performed. The determined parameters are entered into the operation sheet or into the database, which modern injection moulding machines are equipped in. They are also equipped in certain programs which relate to the linearization and hydraulic compensation, wear of the valves and controlling adjustment parameters. However, this process is main reason for the increase in variability. The environment of the company forces very high flexibility of the manufacturing system. It leads to frequent changes of assortment of production and frequent reassembly. Each change in the plastic, even of the same kind but from another manufacturer or the same manufacturer but of other meaning, requires the corrections and re-adjustment of injection process parameters [9, 10].

3. Statistic control methods for process variability

Variability of injection time can be controlled by means of standard statistic process control methods [11, 12]. Widely used tool here is the Shewart's control card.

In order to perform analysis and control the phenomenon of the injection cycle variability the control card was prepared in the spreadsheet. 15 measurements of cycles per minute, 5 samples each have been taken. The results are presented in the Fig. 2.

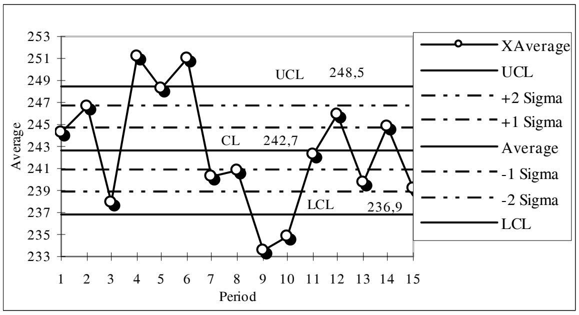


Fig. 2. Monitoring of the injection cycle time by means of Shewart's cards

Mean injection cycle time oscillated near mean value, nevertheless during several measurements the transgressing the boundary lines have been observed. The fundamental influence on the increase in cycle time had the experience and qualifications of the person who operated the machine. In a few cases the mould piece cooling time was shortened. The variability of the injection cycle time had the low or average values.

Hopp and Spearman divided the variability into three categories [6]:

- $c_e^2 < 0.5$ - low variability,
- $0.5 < c_e^2 < 1.75$ - average variability,
- $c_e^2 > 1.75$ - high variability.

After the determination of the changeability phenomenon, its influence on other elements of the manufacturing process by means of computer simulation was investigated because this test could not be performed in a real manufacturing system.

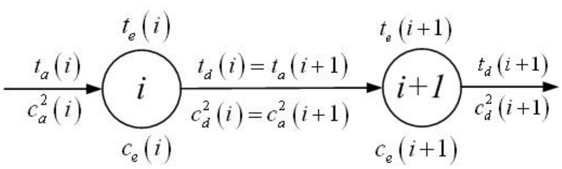


Fig. 3. Propagation of variability in a manufacturing line

where:

i - machine number

t_d - mean time between completion of each jobs,

$1/t_d = r_d$ - frequency of completion of each jobs, productivity

c_d^2 - square variability coefficient of completion of each jobs.

As it is shown in the Fig. 3, the variability of input parameters and machine's operation influences on the output parameters. The output parameters for a technological operation are the input parameters for another operation. As a result of flow, the variability propagation occurs. The characteristics of the behaviour of output parameters, depending on variability of input parameters and workstation operation has been schematically shown in the Fig. 4.

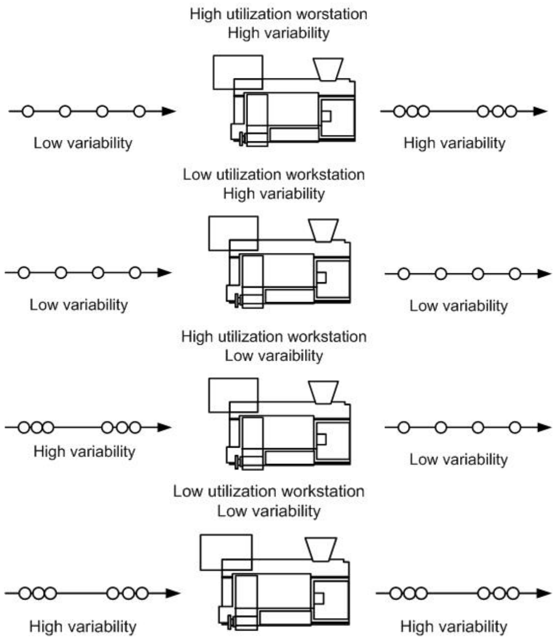


Fig. 4. Dependence of variability of input parameters, operation and output for the workstation

In most cases the machine was medium-utilized or highly-utilized.

4. Computer simulation of production line

The simulation model of a production system have been developed within software *AnyLogic 5.4.1* by XJ Technologies Company Ltd, which employs the system dynamics method (Fig. 5) [13, 14].

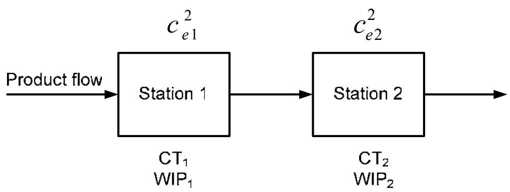


Fig. 5. Simulation model for the production line

The production line with two workstations has been considered. It was assumed, that in order to lessen the effects of injection cycle time variability, the store between workstations would be organized. The amount of the processed material – 100 kg. It was also assumed that the analysed production line was a balanced line with different variabilities of injection cycle time on first workstation and fixed variability on the second workstation. The utilization of both workstations was at the level of 70 %. In the Fig. 6 and 7 the simulation results have been presented.

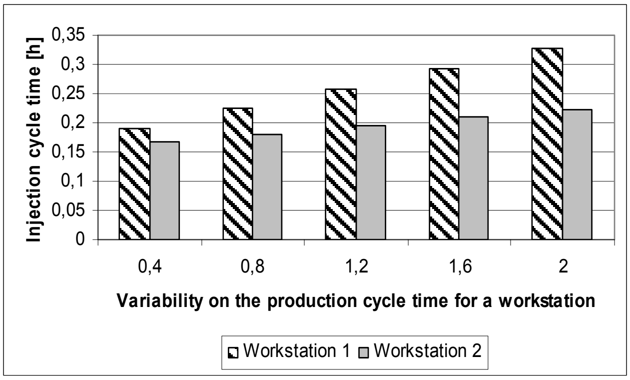


Fig.6. Influence of injection cycle time variability on the production cycle time for a workstation

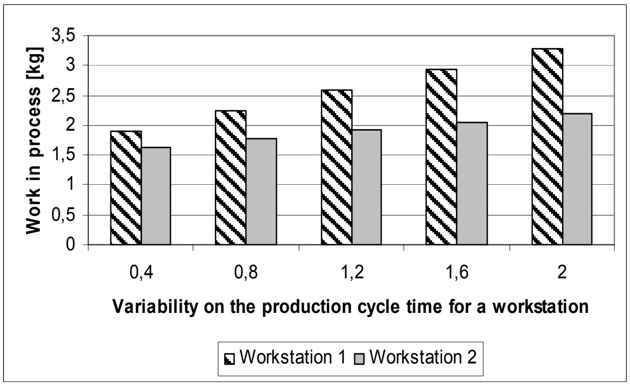


Fig. 7. Influence of injection cycle time variability on the amount of material stored on a workstation

On the basis of manufacturing system simulation it has been observed that the variability in initial workstations has higher influence on the production in progress level than analogically the variability for the stations which realize final production processes.

In steady state the increase of variability of plastic injection cycle time caused the increase in mean production cycle time and the level of production in progress. Moreover, the simulation investigations enabled to observe that while increasing the degree of utilization of the machine u , without other changes, the mean production cycle and production in progress level increases exponentially.

5. Summary

The production managers should consequently strive for reduction in variability of plastics processing parameters because their high variability leads to the extension of production cycles, increase in the production material stocks in progress, poor utilization of production capability and decrease in productivity, which, as a result, generates high production costs. The variability of the polymer material processing parameters not only influences the quality of the manufactured product [15] but also is essential to the whole manufacturing system. It determines, in a fundamental way, the production cycle level and the level of stocks in progress and also determines the flexibility of the system in response to varying conditions e.g. variable demand for the finished products.

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