The statistical researches of flexible manufacturing system's efficiency

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Abstract. Currently engineering production is mainly medium-sized. The parts quantity in batch depends on the customer's requirements (for example, just-in-time delivery) and differs from each other significantly – a range from one to thousand in number. Similar designed products are made by means of flexible manufacturing systems (FMSs). These systems are elaborate and expensive. Therefore, their application needs to be proved. The statistical research allows establishing effective limits of system parameters. The statistical method of Monte Carlo is used for research and allows simulating variation parameters. In article the FMS for production of electric wires contacts is considered. The quantity of such contacts types is estimated in tens. One of important efficiency indicators of FMS is the machine flexibility, which shows system switching ease. The basic element's operation of a manufacturing system and time consumption on its operation on one product is specified. The modelling results are described in the graph's bar in article. The statistical researches method allowed to estimate flexible manufacturing systems efficiency taking batch deviation parts quantity and the changeover need.

1. Introduction

The competitive enterprises face challenges in responding to customer order quickly because the parts quantity in batch is various [1, 2]. Design variability and batches quantity requires the use of statistical modeling methods [3, 4]. Simulation of FMSs function allows establishing limits where flexible production systems are effective [5, 6].

At present, the key characteristics of FMSs effectiveness are: the number of products variations that should be manufactured by this system, and the relative time on FMSs changeover [7]. The research presented below shows the parts quantity in batch also has a significant impact on the FMSs effectiveness. The product quantity of each kind may be varying [8]. The research is conducted by the statistical modeling method.

Figure 1 presents a block-diagram of the FMS for production of electric wires contacts. Figure 2 presents some contacts. The quantity of such contacts types is estimated in tents and the enterprises producing such connectors prefer the flexible production which is quickly adapting by product's design variety, volume and terms of production to the consumer.

Basic elements \((BE_j)\) of the simulated system are: hook hopper feeder \((BE_1)\), loading chute \((BE_2)\), slide damper \((BE_3)\), boring mill turret \((BE_4)\) and back gate \((BE_5)\).
2. Research object model

One of important efficiency indicators of FMS is the machine flexibility, which shows system switching ease. This machine flexibility is defined as $K_{MF}$,

$$K_{MF} = \frac{T_{CH}}{T_{PM} + T_{SR}}$$

(1)

where $T_{CH}$ = time of system changeover, $T_{PM}$ = time of product manufacturing, $T_{SR}$ = time of system restoration and reparation which aren't connected in system changeover, $(T_{PM} + T_{SR})$ = system's usage time.

It is generally accepted that a flexible manufacturing systems are high-flexibility level's systems if $0.1 \leq K_{MF} \leq 0.2$, average-flexibility level's systems if $0.1 < K_{MF} \leq 0.2$ and low-flexibility level's systems if $0.2 < K_{MF}$.

Table 1 shows the main elements of the production system and the time of its work ($t_{op,BEj}$) on one product.

| Basic element, $BEj$ | The basic element's operation (system's usage time) | Time, $t_{op,BEj}$ (s.) |
|----------------------|-----------------------------------------------------|--------------------------|
| $BE1$                | Adjusting the position and transfer of each single product from feeder to a loading chute. Operating diameter of feeder is 400 mm; quantity of hooks – one; angular speed of hook's rotation – 23 rpm | 2.6                      |
| $BE2$                | Movement of part on a loading chute from feeder to the slide damper. Chute's length – 2000 mm. | 0.6                      |
| $BE3$                | Movement of finish part from loading chute to the machining position (slide damper application). | 0.4                      |
| $BE4$                | Boring mill turret’s operation (drilling two holes and thread cutting) | 19.7                     |
| $BE5$                | Movement of product from machining position to the container (back gate application) | 0.4                      |

In table 2 the operations content and time consumption for FMSs elements changeover are specified.

Table 2. An operations content and time consumption for FMSs elements changeover.
| Basic element, $BE_j$ | The operations content for FMSs elements changeover | Time, $t_{ch, BE_j}$ (min.) |
|----------------------|-------------------------------------------------------|----------------------------|
| $BE_1$               | Adjustment of hook's working radius                   | 11.80                      |
| $BE_2$               | Not applicable                                        | 0.00                       |
| $BE_3$               | Position's adjustment of the slide damper and machining | 1.05                       |
| $BE_4$               | Retooling (drill, tap)                                | 7.41                       |
|                      | Adjustment of the CNC-program                         | 1.84                       |
| $BE_5$               | Position's adjustment of the machining and back gate  | 1.05                       |

After the first product was transferred to chute, the next products are passed from feeder, until the chute is filled. Time of transfer is written down by $t_{op, BE_1}$. The chute is filled quickly because machining time ($t_{op, BE_4}$) exceeds transfer time ($t_{op, BE_1}$).

A product leaves a loading chute through time period equal to the sum of machining time $t_{op, BE_4}$ and time of consecutive application of slide damper and back gate application ($t_{op, BE_3} + t_{op, BE_5}$).

Thus, $i$-batch production time by $N_i$-products can be calculated (figure 3) if FMSs elements are ready and there is no operation's break:

$$T_{PMi} = t_{op, BE_1} + t_{op, BE_2} + \left(t_{op, BE_3} + t_{op, BE_4} + t_{op, BE_5}\right)N_i.$$  \hspace{1cm} (2)

![Batch production time](image)

The time of system restoration and reparation $T_{SR}$ are mainly tool’s repairs and can be calculated:

$$T_{SR} = \frac{t_{op, BE_4}N_i}{T} - t_{tr},$$ \hspace{1cm} (3)

where $i = \text{batch number } (i = 1, ..., n)$, $T = \text{tool life}$, $t_{tr} = \text{one tool’s repair time}$.

Therefore, as for $i$-batch, the machine flexibility of FMS can be calculated:

$$K_{MFi} = \frac{t_{ch, BE_1} + t_{ch, BE_2} + t_{ch, BE_3} + t_{ch, BE_4} + t_{ch, BE_5}}{T_{PMi} = t_{op, BE_1} + t_{op, BE_2} + \left(t_{op, BE_3} + t_{op, BE_4} + t_{op, BE_5}\right)N_i + \frac{t_{op, BE_4}N_i}{T} t_{tr}}$$ \hspace{1cm} (4)

As for $n$ consecutive batches, the Machine flexibility of FMS can be calculated:
\[ K_{MF} = \frac{\sum_{i=1}^{n} K_{MF_i} N_i}{\sum_{i=1}^{n} N_i} \]  

(5)

3. Statistical research

The dependences analysis has set the time consumption for FMSs elements changeover \( T_{CH} \) and parts quantity in batch \( N_j \) influence the Machine flexibility most significantly. The statistical method of Monte Carlo is used for a research and its method allows simulating variation of the parameters \([9, 10]\).

The pseudorandom values \( N_i \) were generated in the range from 50 to 500 in numbers products based on uniform probability distribution for \( n = 100 \) of consecutive processed batches parts.

The feeder changeover need was modeled by replacement of feature \( (t_{ch,BE}) \) on the feature \( (k_{ch,i Bet}) \), where \( k_{ch,i} \) = factor of feeder changeover need for \( i \) – parts production: \( k_{ch,i} = 1 \) if changeover is applicable and \( k_{ch,i} = 2 \) if changeover is not applicable.

The factor \( P_{ch} \) of changeover need probability (changeover is necessary for all production batches and \( k_{ch,i} = 1 \)) was set at four standards:
- \( P_{ch} = 0.00 \) – changeover isn’t necessary for all production batches (high-flexibility feeder) and \( k_{ch,i} = 0 \) for all production batches to simulation model;
- \( P_{ch} = 0.33 \) – changeover is necessary for 33% of all production batches (average-flexibility feeder) and \( k_{ch,i} = 1 \) for 33% of random production batches;
- \( P_{ch} = 0.66 \) – changeover is necessary for 66% of all production batches (low-flexibility feeder) and \( k_{ch,i} = 1 \) for 66% of random production batches;
- \( P_{ch} = 1.00 \) – changeover is necessary for all production batches (in-flexible feeder) and \( k_{ch,i} = 1 \) for all production batches to simulation model.

Statistical researches for each level have been made a 100 times that has allowed simulating a significant volume of situations with variable of parts quantity in batch and FMSs changeover quantity. The modeling results are presented in the bar graph, depicted in figure 4. The bar graphs relating separately to various changeover need probability standard are spline integrated.

From histograms it is visible that the FMS can be the high-flexibility level’s system if \( P_{ch} = 0.00 \) \( (K_{MF} = 0.089 \pm 0.015) \). The FMS can be the average-flexibility level’s system if \( P_{ch} = 0.33 \) \( (K_{MF} = 0.121 \pm 0.022) \), \( P_{ch} = 0.66 \) \( (K_{MF} = 0.152 \pm 0.028) \) and \( P_{ch} = 1.00 \) \( (K_{MF} = 0.186 \pm 0.027) \).

Figure 4. Influence of a changeover need’s probability factor on machine flexibility with parts quantity in batch in the range from 50 to 500.
Figure 5 presents a modeling results bar graph is shown for the enterprise initial state. The parts quantity in batch has varied from 200 to 500, all FMSs elements were changeovers when a new size/design product began to be made $P_{ch} = 1.00 \ (K_{MF} = 0.143 \pm 0.012)$.

![Figure 5](image_url)

**Figure 5.** Influence of a changeover need's probability factor on machine flexibility with parts quantity in batch in the range from 200 to 500.

The modeling results are determined in accord with probability belief of 90% and with supposition that the constructed distributions are centrally symmetric. Highest precision in results assessment wasn’t required at this stage.

4. **Conclusions and recommendations**

1. The statistical researches method has allowed estimating flexible manufacturing system’s efficiency with due regard for parts quantity in batch deviation and the changeover need.

2. The parts quantity in batch varied has significant impact on FMSs efficiency. The FMSs with parts quantity in batch from 200 to 500 by indicator of machine flexibility can be estimated by average-flexibility level's system, but with quantity from 50 to 500 – by low-flexibility level's system.

3. The executed modeling has shown the application of low-flexibility feeder allows to downgrade of machines flexibility index almost on ~25 % in comparison with in-flexible feeder, the application of average-flexibility feeder – to downgrade by ~50 %, the application of high-flexibility feeder – to downgrade ~100 %. The use of high-flexible devices is the perspective direction of FMSs creation.

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