ADEKO
MAY 18TH 2010, 50TH ANNIVERSARY
OF THE FACULTY OF TECHNICAL SCIENCES, NOVI SAD
MACHINE DESIGN
ISSN 1821-1259

THE MODELING AND DESIGNING OF FLEXIBLE SYNCHRONOUS PRODUCTION LINE WITH REDUNDANT TECHNOLOGICAL CELL

Oleg FILIPOVICH
Victor TARANENKO
Antoni SWIC
Lech MAZUREK

Abstract: *The paper introduces a mathematical model of operation of a flexible synchronous production line (FSPL) of multifunctional CNC machines that includes one redundant multifunctional CNC machine which can take over the functions of every FSPL machine. The optimization of the number of machine tools considering the efficiency of FSPL was conducted during designing of FPSL. The graph of FSPL state, relations and equations used to calculate reliability and productivity were shown. Maple, the software used for reliability and productivity calculations and modeling, as well as the mathematical results are presented.*

Keywords: *model, flexible, synchronous production line, technological cell*

1. INTRODUCTION

Multi-role CNC machines are mainly designed for processing frame type parts which have many holes with different diameters and precision (class 5 to 11), on which resistance points are based, and additional tools are connected to the frame and to mounting connections (to attach the part using screws or pegs and to facilitate processing, establishing datums, and assembly). The dimensions of the main hole diameters vary within a wide range (from 16 to 50 mm) and depend on the type of part [1]. The work [2] introduces specification of processing and classification of holes for the system of automated design of technological processes. Modern market conditions require production characterized by quick start and quick change of the assortment of produced parts. CNC machine tools and Flexible Production Systems (FPS), combing the high flexibility of traditional equipment and the high efficiency of machine tools, are the most effective equipment for multi-nomenclature production.

2. METHODOLOGY OF MODELING FSPL RELIABILITY AND EFFICIENCY

Every multi-role CNC machine tool can be considered as a complex system. If the system contains "n" number of serial connected elements, damage of any of them leads to the failure of the whole system and can be described by graph [3, 4].
States on the graph: S0 – all n elements of the system are operating; S1 – the first element failed and the system is non-operational; S2 – the second element failed and the system is out of order; . . ; Sn – nth element failed and the system is not working.
Indications on the graph:
$\lambda_i, \left(i=1,\overline{n}\right), \mu_i, \left(i=1,\overline{n}\right)$ – the intensity of failure and restoration stream of working ability of 1 to n elements.
Because of the fact that after failure of any element the rest of the elements cannot function properly until the time of restoration of its work ability, it is considered that only one element can fail at a time. All failure and restoration streams are considered as simple.

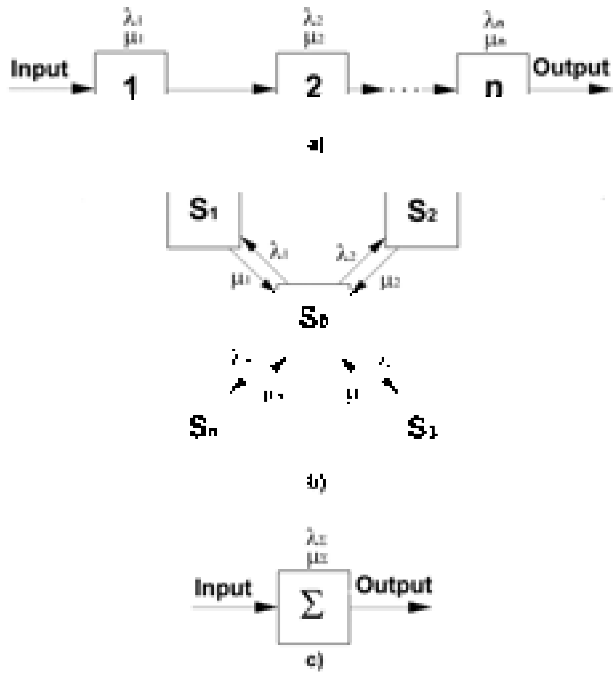


Fig. 1. The conditions graph of the multirole CNC machine tool: a) system elements from 1 to n; b) elements conditions; c) machine as the sum of all elements

The system of equations for the qualification of final probabilities is presented below:

$$\begin{cases} P_0\sum_{i=1}^{n}\lambda_i = \sum_{i=1}^{n}P_i\mu_i; \\ P_1\mu_1 = P_0\lambda_1; \\ P_2\mu_2 = P_0\lambda_2; \\ .... \\ P_i\mu_i = P_0\lambda_i; \\ .... \\ P_n\mu_n = P_0\lambda_n. \end{cases} \quad (1)$$

The standardization condition:

$$\sum_{j=0}^{n} P_j = 1. \qquad (2)$$

After change of the first equation of system (1) to the standardization condition (2) and solutions, every probability $P_i, (i = \overline{1,n})$ is expressed by P_0:

$$P_i = P_0 \frac{\lambda_i}{\mu_i}. \qquad (3)$$

The set of numbers i is marked as I ($i \in I$). Let us introduce the j, belonging to this set: $j \in I$. With regard of new letters, after the substitution of 3 to the standardization condition 2 the following formula is received:

$$P_0 = \frac{1}{1 + \sum_{j=1}^{n} \frac{\lambda_j}{\mu_j}}. \qquad (4)$$

After substitution of (4) to (3):

$$P_i = \frac{\lambda_i}{(1 + \sum_{j=1}^{n} \frac{\lambda_j}{\mu_j})\mu_i} = \frac{\rho_i}{1 + \sum_{j=1}^{n} \rho_j}, \qquad (5)$$

where: $\rho_i = \frac{\lambda_i}{\mu_i}, \rho_j = \frac{\lambda_j}{\mu_j}$.

The output system (Fig.1) is replaced with the simple two-state element: working and non-work (in the damage condition; non-operational). The diagram of such an element or new system is introduced in Fig. 2.

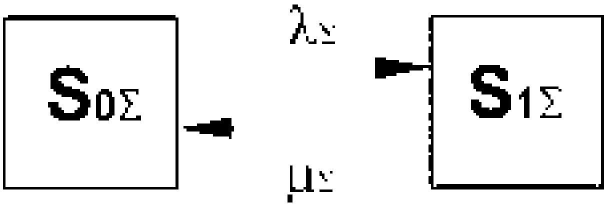


Fig. 2. Diagram of the system element

where λ_Σ is defined as:

$$\lambda_\Sigma = \sum_{i=1}^{n} \lambda_i. \qquad (6)$$

The value μ_Σ is defined from dependence:

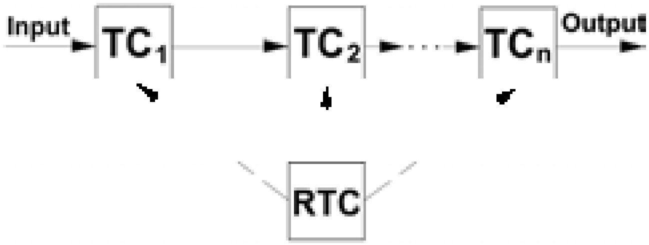
$$\mu_\Sigma = \frac{P_0}{1 - P_0} \lambda_\Sigma \qquad (7)$$

After substitution of (4) to (7) the following formula is received:

$$\mu_\Sigma = \frac{\lambda_\Sigma}{\sum_{j=1}^{n} \rho_j}. \qquad (8)$$

3. THE MATHEMATICAL MODEL OF FSPL FUNCTIONING

At present we use the structure of the flexible synchronous production line (FSPL) from the multi-role CNC machine tools with a redundant technological cell (RTC) which can replace any multi-role machine – technological cell (TC). Fig.3 introduces the structure of such a flexible system (FSPL).



The redundant technological cell (RTC) can replace only one damaged machine (TC), so whole system (FSPL) stops to work after failure of two machines (TC) [5].

Fig.3. The FSPL structure

The graph of states (FSPL), including RTC, is introduced on fig. 4. States on the graph:

S_0 - all multirole machines (TC) are operating; S_1 - 1[e] TC_1 does not operate; S_2 - 2[e] TC_2 does not operate; … , S_n - n - e TC_n does not operate; $S_{1,1}$ - second TC_2 failure while TC_1 does not operate; . . $S_{1,2}$ - third TC_3 failure while TC_1 does not operate; …; $S_{1,n-1}$ - the n – e TC_n failure while TC_1 does not operate; $S_{2,1}$ - first TC_1 failure while TC_2 does not operate; $S_{2,2}$ - third TC_3 failure while TC_2 does not operate; …; $S_{2,n-1}$ the n - e TC_n failure while TC_2 does not operate; $S_{3,1}$ - first TC_1 failure while TC_3 does not operate; $S_{3,2}$ - second TC_2 failure while TC_3 does not operate; $S_{3,3}$ - (not shown on graph) the TC_4 failure while TC_3 does not operate; ... ; $S_{3,n-1}$ - the n–e TC_n failure while TC_3 does not operate; $S_{i,1}$ - first TC_1 failure while TC_i does not operate; $S_{i,2}$ - second TC_2 failure while TC_i does not operate; … ; $S_{i,n-1}$ - failure n-e TC_n while TC_i does not operate; $S_{n,1}$ - first TC_1 failure while TC_n does not operate; $S_{n,2}$ - second TC_2 failure while TC_n does not operate; … ; $S_{n,n-1}$ - n–1 - e TC_n failure while TC_n does not operate; States $S_0, S_1, S_2, S_3, S_4, ..., S_n$ - able to work and remaining for an emergency. Graph clarification: $\lambda_i (i = \overline{1,n}); \mu_i (i = \overline{1,n})$ - intensity of the failure stream and restoring the working ability of technological devices TC_i $i = \overline{1,n})$.

The number of states is considerable (e.g. for n = 10 the number of states is $N = n^2 + 1 = 101$, which makes model construction and analysis difficult). That is the approach based on the increase of states is proposed.

We isolate the following subsets in E set (power N):

$E_1 = \{S_1, S_{1,1}, S_{1,2}, ..., S_{1,n-1}\}$; $E_2 = \{S_2, S_{2,1}, S_{2,2}, ..., S_{2,n-1}\}$;

$E_3 = \{S_3, S_{3,1}, S_{3,2}, ..., S_{3,n-1}\}$;

…; $E_i = \{S_i, S_{i,1}, S_{i,2}, ..., S_{i,n-1}\}$; …;

$E_n = \{S_n, S_{n,1}, S_{n,2}, ..., S_{n,n-1}\}$.

We will qualify the probability of system existence in these subsets. In this case we will consider a diagram of equivalent enlarged system shown in Fig. 4.

States on the diagram (Fig.4):

S_0 - all multirole CNC machine tools are operating; $S_{1\sum}$ - the system is in one of states of the E_1 subset; $S_{2\sum}$ - the system is in one of the states of E_2 subset; … ; $S_{n\sum}$ - the system is in one of states of the E_n subset.

On the graph: $\lambda_i, (i = 1,\overline{n})$ - is the intensity of the failure streams $UT_i, (i = 1,\overline{n})$; $\mu_{i0}, (i = 1,\overline{n})$ - the intensity of the stream restoring the system working ability from subsets $E_i, (i = 1,\overline{n})$.

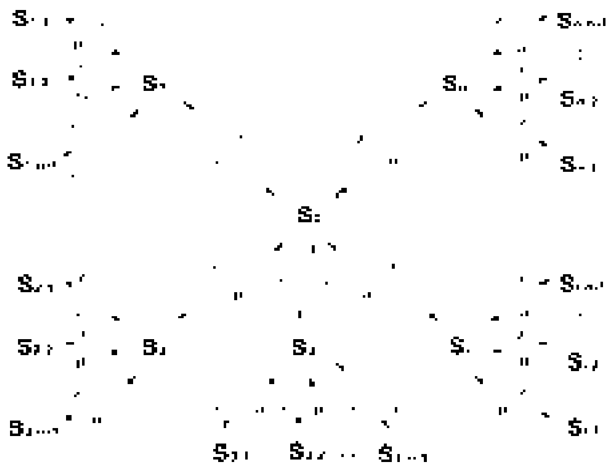


Fig. 4. Graph of FSPL conditions, including one reserved RTC place

The task consists in defining $\mu_{i0}(i = 1,\overline{n})$. If all diagram (Fig. 4) conditions probabilities are known, then $\mu_{i0}(i = 1,\overline{n})$ can be determined from the dependence:

$$\mu_{i0} = \frac{P_i}{P_i + \sum\limits_{j=1(j \neq i)}^{n-1} P_{ij}} \mu_i \qquad (9)$$

where P_{ij} - the states probability of $S_{ij} \in E_i$, the rate before μ_i in (1), equal $\frac{P_i}{P_i + \sum\limits_{j=1(j \neq i)}^{n-1} P_{ij}}$, then conditional probability, that it is include in the subset of states E_i, the system is in the state S_i.

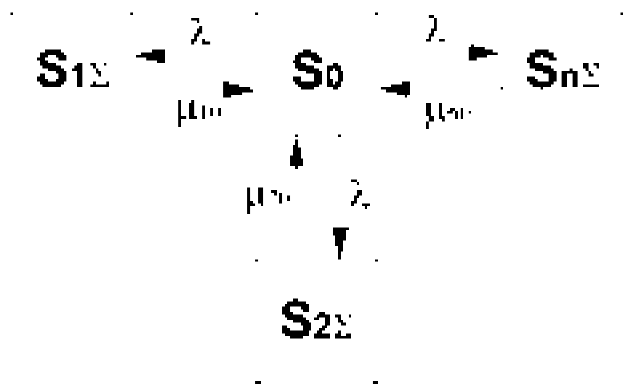


Fig. 5. Diagram of conditions equivalent of enlarged system

We will mark the component of E set as $S_k, (k = 1,\overline{N})$, ($S_k \in E$). Dividing the numerator and the nominative (1) by the probability of system being in the E_i $P_{iz} = P\{S_k \in E_i\} = P_i + \sum\limits_{j=1(j \neq i)}^{n-1} P_{ij}$ subset, we will receive:

$$\mu_{i0} = \frac{P_i}{P_{i\sum}} \mu_i = P_{iy} \mu_i \qquad (10)$$

where P_{iy} - the conditional probability of system being in the S_i state.

We will qualify the conditional probability of the elements of E_i subsets:

$P_{iy} = P\{S_k = S_i / S_k \in E_i\}; P_{ijy} = P\{S_k = S_i / S_k \in E_i\}$. They are equal:

$$P_{iy} = \frac{P_i}{P_{i\sum}}, \qquad (11)$$

$$P_{ijy} = \frac{P_{ij}}{P_{i\sum}} = \frac{P_{ij}}{P_i + \sum\limits_{j=1(j \neq i)}^{n-1} P_{ij}}. \qquad (12)$$

To determine the probabilities P_{iy} and $P_{ijy}, (i = 1,\overline{n}; j = 1\overline{n-1})$ we should consider subsets $E_i, (i = 1,\overline{n})$ as independent subsets. For comfort, the set of numbers j is marked as J, ($j \in J$). Let us introduce numbers m, also belonging to this subset ($m \in J$).

With regard of the new numbers of dependence to determine P_{iy} and P_{ijy} we get:

$$P_{iy} = \frac{1}{1 + \sum\limits_{j=1(j \neq i)}^{n-1} \rho_j}, \quad (13)$$

$$P_{ijy} = \frac{\rho_j}{1 + \sum\limits_{m=1(m \neq i)}^{n-1} \rho_m}, \quad (14)$$

where $\rho_j = \frac{\lambda_j}{\mu_j}, \rho_m = \frac{\lambda_m}{\mu_m}$ - the imported intensities of streams.

Substituting (13) in (10) we will receive:

$$\mu_{i0} = (1 + \sum_{j=1(j \neq i)}^{n-1} \rho_j)^{-1} \mu_i \ . \quad (15)$$

All intensities in the diagram (Fig.5) are known, and the probability of states $P_0, P_{1\Sigma}, ..., P_{i\Sigma}, ..., P_{n\Sigma}$ is defined according to well-known dependences [3]:

$$P_0 = \left[1 + \sum_{i=1}^{n} \rho_i (1 + \sum_{j=1(j \neq i)}^{n-1} \rho_j) \right]^{-1}, \quad (16)$$

$$P_{i\Sigma} = \left[1 + \sum_{i=1}^{n} \rho_i (1 + \sum_{j=1(j \neq i)}^{n-1} \rho_j) \right]^{-1} \rho_i (1 + \sum_{j=1(j \neq i)}^{n-1} \rho_j) \ . \quad (17)$$

After calculations according to relations (16) (17), the graph probability conditions, introduced in Fig. 5, can determine the probability of states $S_i (i = 1, \overline{n})$ and $S_{ij} (i = 1, \overline{n}; j = 1, \overline{n-1})$ of the diagram, introduced in Fig. 3. According to (11), (12) and (13),(14):

$$P_i = P_{iy} P_{i\Sigma} = (1 + \sum_{j=1(j \neq i)}^{n-1} \rho_j)^{-1} P_{i\Sigma} \ , \quad (18)$$

$$P_{ij} = P_{ijy} P_{i\Sigma} = \frac{\rho_j}{1 + \sum\limits_{m=1(m \neq i)}^{n-1} \rho_m} P_{i\Sigma} \ . \quad (19)$$

After substituting (17) in (18) and (19) :

$$P_i = \left[1 + \sum_{i=1}^{n} \rho_i (1 + \sum_{j=1(j \neq i)}^{n-1} \rho_j) \right]^{-1} \rho_i \ , \quad (20)$$

$$P_{ij} = \left[1 + \sum_{i=1}^{n} \rho_i (1 + \sum_{j=1(j \neq i)}^{n-1} \rho_j) \right]^{-1} \rho_i \rho_j \ . \quad (21)$$

The whole initial structure of the flexible synchronous line (FSPL) pf multi-role CNC machine tools, including reserve working place (RTC), is replaced through one simplest equivalent element for which the intensities of the failures streams λ_Σ and the restoration of efficiency μ_Σ are known. An element with two states is considered as the simplest: the standby and the working state. A diagram of conditions of such an element is shown in Fig.6.

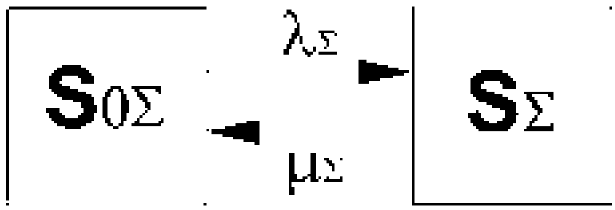


Fig. 6. Graph of FSPL conditions, referred to the simplest element

States in the diagram: $S_{0\Sigma}$ - able to the work; S_Σ - broken (unable to work). We will introduce two new subsets of states for the diagram in Fig. 4: U - able to work , encircled with dashed line, and V - incapable of working:

$$U = \{ S_0, S_1, ..., S_i, ..., S_n \}$$

$$V = \begin{Bmatrix} S_{1,1}, ..., S_{1,j}, ..., S_{1,n-1}, ..., S_{i,1}, ..., \\ S_{ij}, ..., S_{i,n-1}, ..., S_{n,1}, ..., S_{n,j}, ..., S_{n,n-1} \end{Bmatrix}$$

The subset U answers state $S_{0\Sigma}$ introduced in Fig. 6, and the subset V - state S_Σ The probability of the system being in states $S_{0\Sigma}$ and S_Σ is equal to:

$$P_{0\Sigma} = P_0 + \sum_{i=1}^{n} P_i \ , \quad (22)$$

$$P_\Sigma = 1 - P_{0\Sigma} = \sum_{i=1}^{n} \sum_{j=1(j \neq i)}^{n-1} P_{ij} \ . \quad (23)$$

Intensities λ_Σ and μ_Σ for graph introduced on fig. 6 are equal to:

$$\lambda_\Sigma = \sum_{i=1}^{n} \left(\frac{P_i}{P_{0\Sigma}} \sum_{j=1(j \neq i)}^{n-1} \lambda_j \right) = \sum_{i=1}^{n} \left(\frac{P_i}{P_0 + \sum\limits_{i=1}^{n} P_i} \sum_{j=1(j \neq i)}^{n-1} \lambda_j \right), \quad (24)$$

$$\mu_\Sigma = \sum_{i=1}^{n} \sum_{j=1(j \neq i)}^{n-1} \frac{P_{ij}}{P_\Sigma} \mu_j = \sum_{i=1}^{n} \sum_{j=1(j \neq i)}^{n-1} \frac{P_{ij}}{\sum\limits_{j=1}^{n} \sum\limits_{j=1(j \neq i)}^{n-1} P_{ij}} \mu_j \ . \quad (25)$$

4. PROGRAM FOR DEFINING FSPL RELIABILITY AND EFFICIENCY

The program for defining the parameters of functioning of synchronous FSPL was written in the mathematical software for analytic calculations – Maple. This environment is a powerful computer tool, able the solve complex mathematical tasks. It contains tools related to many mathematical fields (algebra, discreet mathematics, differential and integral mathematics, numerical and different methods) and also allows graphical representation, and connection to external modules and programming tools. The algorithm of calculating the parameters of functioning the FSPL was worked out. All calculations were carried out for the universal machining CNC center KORRADI VH 1000 that is part of production lines to engine frames of vehicle Tavria Nova (1200 cm^3 i 63 KM) within the department of the stock corporation „AvtoZAZ-Motor" in Melitopol Ukraine. The simulations were conducted for FSPL which consists of vertical machining center CINCINNATI SABRE 1000 and vertical machining center CINCINNATI ARROW 1000.

The components of the program:

1. Block pastern of the input data.
2. The block of the calculation of required parameters functions of the synchronous line with (without) the reserve place.
3. Block of formatting results of the experiment and output for these results.

Input data to the execution of research:

1. Maximum number of cells in the line N;
2. Intensity of the stream of damage λ_i and restoring the working ability μ_i of every unit ($i = \overline{1, N}$);
3. Average time of service for every production individual cell t_i ($i = \overline{1, N}$);
4. Step of calculations Δn (total number equal to the difference between the values of two of the current number of cells in line n of neighbouring cycles).

The block of calculations comprise the following operations:

1. Defining intensities of streams $\rho_i = \dfrac{\lambda_i}{\mu_i}$, $i = \overline{1, N}$
2. Qualification of the intensity $\mu_i 0$ according to dependence (15).
3. Calculation of the probability P_0 according to dependence (16).
4. Calculation of the probability $P_{i\Sigma}$, P_i, P_{ij} according to dependence (17), (18), (21) respectively.
5. Qualification of the rate of the readiness of the line $K_G = P_{0\Sigma}$ according to dependence (22).
6. Calculation of the efficiency of the line: $P = \dfrac{1}{t_{\max}} K_G$,

where $t_{\max}$ - maximal time among average times of service for every production cell

7. Defining the parameters of functioning of the synchronous line not including the reserve place:

- the rate of readiness of the line $K'_G = \dfrac{1}{1 + \sum_i \rho_i}$,

- the efficiency of the line $P' = \dfrac{1}{t_{\max}} K'_G$.

8. Calculation of current values

- increase of the coefficient of readiness of the line as absolute value $\Delta K_G = K_G - K'_G$

in percentages $\delta K_G = \dfrac{\Delta K_G}{\max\{K_G, K'_G\}} 100\%$

- increase of the efficiency of the line as absolute value

$$\Delta P = P - P'$$

in percentages

$$\delta P = \frac{\Delta P}{\max\{P, P'\}} 100\%$$

These calculation are taken cyclically until the condition $n = N$ is not met. After that the programme works out the results of the experiment (increase of efficiency) and presents the results on the screen as a matrix and a chart. The charts of increase of FSPL efficiency after changing parameters λ and μ were introduced in Fig. 7, 8, 9.

5. THE RESULTS OF CALCULATIONS

5.1 Line with the Maximum Number TC Equal to 10

The parameters of reliability and service of all TCs are equal to

λ = 0,2 (h^{-1})

μ = 5 (h^{-1})

t = 0,1 (h)

MATRIX OF EFFICIENCY INCREASE

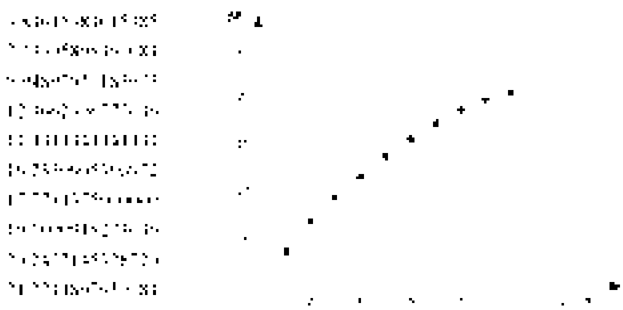


Fig. 7. Graph of FSPL efficiency increase
MAXIMUM INCREASE = 21.224489795918

5.2. Line with the Maximum Number of TC Equal to 10

The parameters of reliability and service of all TCs:

λ = 0,25 (h^{-1})

μ = 4 (h^{-1})

t = 0,1 (h)

MATRIX OF EFFICIENCY INCREASE

Fig. 8. Graph of FSPL efficiency increase|
MAXIMAL INCREASE = 25.1479289940828

5.3. Line with the Maximum Number of TC Equal 10

The parameters of reliability and service of all TCs:

$$\lambda = 0{,}3\ (h^{-1})$$

$$\mu = 3\ (h^{-1})$$

$$t = 0{,}1\ (h)$$

MATRIX OF EFFICIENCY INCREASE

Fig. 9. Graph of FSPL efficiency increase
MAXIMAL INCREASE = 27.500000000000

6. OPTIMIZATION OF THE NUMBER OF MACHINE TOOLS IN THE FLEXIBLE SYNCHRONOUS PRODUCTION LINE

The process of running the flexible synchronous production line (FSPL) which consists of consecutively connected technological machines (TM) with one stand-by technological machine (STM) is considered in the paper (Fig. 3).

The line consists of technological machines of one type in number of *n* (TM_1, …, TM_n) and one stand-by technological machine STM which is able to replace every single machine of TM system (the simulation was carried out for FSPL in a.m. enterprise „AvtoZAZ-Motor" in Melitopol).

In references [5] they present the model of functioning the FSPL but the whole line's structure is exchanged, according to reliability parameters, for the simple equivalent element with two states (working and emergency), defining its functioning indexes:

1) the intensity of failure and restoration stream of working ability;
2) expected value of the production unit service time;
3) availability factor;
4) efficiency ratio taking into consideration reliability parameters.

By creating the model they assumed that all streams which carry the system from one state to another are simple and service times are disposed exponentially. However the intensity of failure stream λ_i and restoration stream of working ability μ_i and also service times t_i in every TM_i are different.

The given model differs from the one in references [6] with equal quantities.

The aim of the model was to define the productivity gain that is the difference of productivity of FSPL with STM and productivity without STM:

$$\Delta\ddot{P} = \ddot{P} - \ddot{P}'$$

The analysis of the results obtained by applying the model shows, that by increasing the number of machine tools in the line the diagram of the productivity gain is like the one shown in Fig. 10.

First, the diagram increases steeply right up to the maximum, then it decreases fluently together with increasing number of TM in the line and the diagram can practically reach the zero. It is obvious because by significant increasing the number of TM in FSPL, one STM cannot manage to replace the fixed number of TM, well the productivity of FSPL with STM is equal the productivity of FSPL without STM.

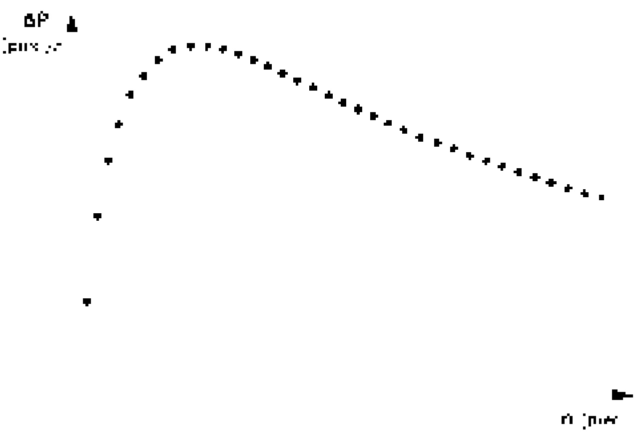


Fig. 10. Approximate diagram of the productivity gain vs number of TM

The task's optimization is found here, it lies in the fact, that it is necessary to define the number of TM in FSPL with STM which allows to attain the maximum productivity gain. This is the task of integer programming without reservation (taking into consideration that number of TM is even). The solution shouldn't be worried out by specially developed algorithm, it is better to choose the quick choice process which consists in the repeatable procedure in cycles, in each step *j* of the mathematical model (in references [5]) for the current number of technological machines TM_j it defines the availability factor of FSPL with STM and without STM and also its productivity ($\ddot{P}_j$, i $\ddot{P}'_j$ - accordingly). The productivity gain $\Delta\ddot{P}_j$ is defined. If $\Delta\ddot{P}_j > \Delta\ddot{P}_{j-1}$ then the current number of TM in the line - n_j is assumed as the optimum point $n_{\ddot{P}\ddot{P}'\delta}$. Otherwise the cycle can be stopped. The conditioning of unimodular target function (there is the only extreme that is the global extreme) is confirmed by findings of research with different parameters. In that procedure the quantity *j* is being changed from 1 to $n_{\ddot{P}\ddot{P}'\delta}$ and at the beginning of the cycle $n_{\ddot{P}\ddot{P}'\delta} = 1$.

The program of searching for optimal number of technological machines is realized in the mathematical software Maple 9. The solutions of the tasks is going to be presented here.

The intensity of failure and restoration stream of working ability and also the service times for every single machine tool are assumed to be equal. The presented below research is connected with defining the influence of reliability parameters on optimal number of machine tools in the line by fixed service times [7].

1. Reliability parameters are to be changed depending on the intensity of failure of every single machine tool λ_i = 0,25…0,35 h^{-1} with constants μ_i = 3 h^{-1} and t_i = 0,05 h (Fig. 11).

Maximum productivity gain and optimal number of machine tools are:
- in first case: ΔP_{max} = 27,90 pcs./h, n_{opt} = 9 pcs.
- in second case: ΔP_{max} = 27,50 pcs./h, n_{opt} = 10 pcs.
- in third case: ΔP_{max} = 27,08 pcs./h, n_{opt} = 12 pcs.

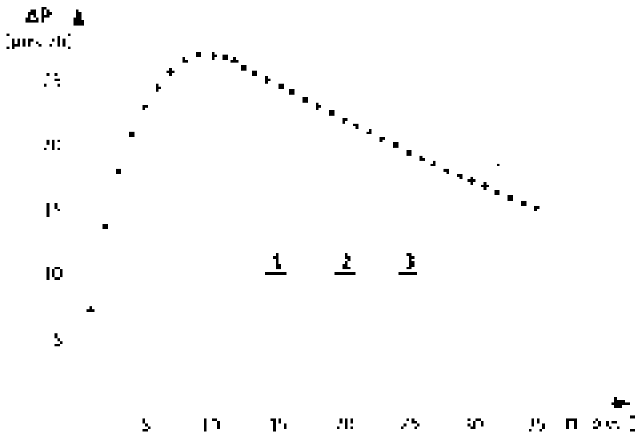


Fig.11. Diagram of *the productivity gain vs number of TM by parameters quantities*: 1 - $\lambda_i = 0{,}35\ h^{-1}$, $\mu_i = 3\ h^{-1}$, 2 - $\lambda_i = 0{,}30\ h^{-1}$, $\mu_i = 3\ h^{-1}$, 3 - $\lambda_i = 0{,}25\ h^{-1}$, $\mu_i = 3\ h^{-1}$

2. Reliability parameters are to be changed depending on the intensity restoration stream of working ability of every single machine tool λ_i = 3…5 h^{-1} with constants μ_i = 3 h^{-1} i t_i = 0,1 h (Fig. 12).

Maximum productivity gain and optimal number of machine tools are:
- in first case: ΔP_{max} = 27,50 pcs./h, n_{opt} = 10 pcs.
- in second case: ΔP_{max} = 26,87 pcs./h, n_{opt} = 13 pcs.
- in third case: ΔP_{max} = 26,49 pcs./h, n_{opt} = 17 pcs.

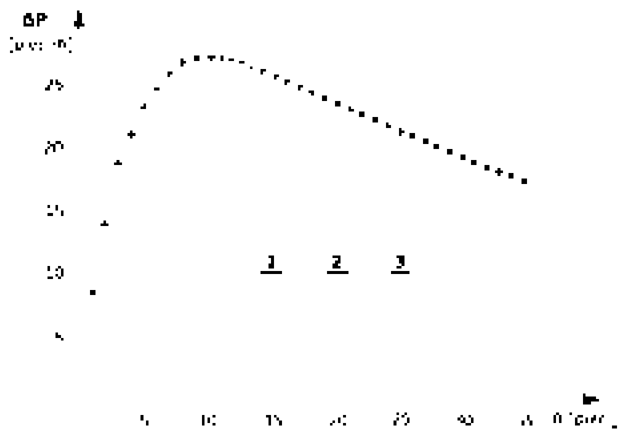


Fig. 12. Diagram of the productivity gain vs number of TM by parameters quantities: 1)$\lambda_i = 5\ h^{-1}$, $\mu_i = 3\ h^{-1}$, 2)$\lambda_i = 4\ h^{-1}$, $\mu_i = 3\ h^{-1}$, 3)$\lambda_i = 3\ h^{-1}$, $\mu_i = 3\ h^{-1}$

7. CONCLUSIONS

A methodology is presented for modelling CNC machine tools and FSPL. A mathematical model of machine tools and FSPL as a structure of elementary technological cells has been developed. The obtained results relate to machining in flexible systems that are wholly brand-name.

An algorithm has been developed for the calculation of parameters of FSPL operation. All the calculations were made for the universal CNC machining centre KORRADI VH 1000, included in the production line for machining engine blocks of the vehicle Tavria Nova (1200 cm^3 and 63 KM) at the production department of the Company „AvtoZAZ-Motor" in Melitopol, Ukraine. Simulations were performed for FSPL that incorporates a vertical machining centre CINCINNATI SABRE 1000 and a vertical machining centre CINCINNATI ARROW 1000.

The results of the simulation showed that the maximum gain in productivity: ΔP_{max} = 27.90 pcs /h, and the optimum number of machine tools n_{opt} = 9 pcs, were obtained at the level of damage stream intensity for each machine tool of λ_i = 0,25 ...0,35 h^{-1} and for constants μ_i, = 3 h^{-1} and t_i = 0,05 h.

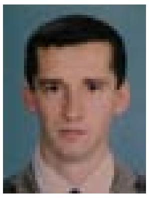
The results of simulation showed that the maximum gain in productivity: ΔP_{max} = 27.50 pcs /h, and the optimum number of machine tools n_{opt} = 10 pcs, were obtained for the value of intensity of stream of restoration to work for each machine tool of λ_i = 3...5 h^{-1} at constants μ_i, = 3 h^{-1} and 7,= 0,1 h.

The given values of intensity of streams of damage of each machine tool λ, and of restoration to work μ, and t_i were obtained at the aforementioned Company. The obtained results of simulations of gain in productivity and the optimum numbers of machine tools indicate that with deterioration in reliability parameters there is a decrease in the optimum number of machine tools, but for a specific number of machine tools the gain in productivity is higher than for a line with analogous parameters of maintenance and better indices of reliability.

REFERENCES

[1] SWIC A.: Elastyczne systemy produkcyjne. Technologiczno-organizacyjne aspekty projektowania i eksploatacji. Wydawnictwo Politechniki Lubelskiej, Lublin (1998)
[2] MAZUREK L., SWIC A., TARANENKO V.: Holes processing and classification in automated technological process projecting system. Acta Mechanica Slovaca**,** Journal published by Faculty of Mechanical Engineering, the Technical University in Kosice, Kosice, 2-A/2006, Rocnik 10. – s.325 – 330 (2006)
[3] SWIC A., TARANENKO V.: Projektowanie technologicznych systemów produkcyjnych. Wydawnictwo Politechniki Lubelskiej, Lublin (2003)
[4] TARANENKO V. A., TCZUB O. P.: Sistemnyj podchod k sintezu GAL mechanoobrabotki: Avtomatizacja processov i upravlenije, Viestnik SevGTU, Sevastopol: wyp.7, 1997 (1997)
[5] FILIPOWICZ O., MAZUREK L., TARANENKO V., SWIC A.: Model matematyczny funkcjonowania elastycznej linii produkcyjnej. Pomiary. Automatyka. Robotyka. Miesiecznik naukowo – techniczny, nr 2/2007, Warszawa (2007)
[6] MAZUREK L., FILIPOWICZ O., TARANENKO W., ŚWIĆ A.: *Model procesu przezbrajania wielozadaniowych obrabiarek NC w elastycznym systemie produkcyjnym.* Przegląd Mechaniczny No.5/2007, Suplement. S. 104-106
[7] ПАШКОВ Е.В. *Транспортно-накопительные и загрузочные системы в сборочном производстве* /Е.В. Пашков, В.Я. Копп, А.Г. Карлов. – К.: УМК ВО, 1992. – 536 с.

CORRESPONDENCE



Oleg FILIPOVICH Doc. Ph D. Eng.
Sevastopol National Technical University
Universyteckaya 33, 99-053
Sevastopol, Ukraine,
phiol@ukr.net

Victor TARANENKO Prof. PhD, D.Sc., Eng, Head of Flexible Manufacturing Systems Department
Institute of Technological and Information Systems
Lublin University of Technology
Nadbystrzycka 36
20-618 Lublin, Poland
w.taranenko@pollub.pl

Antoni ŚWIĆ, PhD, D.Sc., Eng., (Accos. Prof.), The Head of Institute of Technological Systems of Information
Lublin University of Technology
Nadbystrzycka 36
20-618 Lublin, Poland
a.swic@pollub.pl

Lech MAZUREK, M.Sc. Eng, assistant
The State School of Higher Education in Chelm
Pocztowa Str. 54, 22-100 Chelm, Poland
lmazurek@pwsz.chelm.pl