

Study of Availability and Productivity of Automated Lines

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ABSTRACT

In area of manufacturing, the indices of each manufacturing machine are the productivity and goodness of products. The theory of reliability is closely related to indices of productivity, the both theories the efficiency of machines, and optimizations one. The reliability of machines has been guessed by standard indices of the theory of reliability. The main index of reliability of every manufacturing machine is its availability. However, indicated the reliability of industrial machines with complicate design have not expressed in equations of the productivity. These indices of accuracy should be a component of equations of a productivity of a machine and reflects changes of a productivity rate one on changes of indices of reliability and mechanical parameters of a machine. The availability has been included the equations of the machines productivity rate, therefore the reliability of machines is the integrated indication. The machines reliability with complicate design such as automated lines relies also on construction and technical data. The output modelling has been reported the output result with availability for the automated lines, defining their structures according to the grade of reliability and productivity as a task of technical motif of manufacturing machines with complex designs.

Keywords- Reliability, Indices, Industrial Machines.

I. INTRODUCTION

The mathematical models have been presented the industrial automated lines of productivity for the manufacturing machines with complex design [1-3]. Modrres and Toshio Nakgawa have been introduced the flow lines of manufacturing for the productivity and availability with independent of working machines from probability model [4-6]. Other researchers explained the buffering of automated lines with varies processing times of stations of the productivity. The previous studies were not considering indices of reliability such as rate of failure, mean of repairing time of machine units and terminals and do not explain the productivity of machines dependencies on many parametrical natures of performing one. The efficiency of machines is deemed useless, which mounted on kinematics, accuracy, reliability, stresses, and dynamics. The techniques are often struggling for high value of productivity and machined parts quality, whereas they will hence income

and collapse market. The efficiency of machine is a main index productivity, which is depends on a machine of reliability and value of quality of utilization. The productivity of a machine has been directly described analytically. Theory of reliability indices accord standard indices and style of computation of the reliability for complicate systems. However, known indices and models of the machine reliability reported separately on the productivity of machine [5-6]. Mathematical models of machine productivity confer capability to contain norm of indices of thoroughness as characters of formula of the productivity rate for varies designs and construction of machines [7]. Also, analytical realization shows that main indicator of reliability of the manufacturing machines with complicate layout confer standard indices of reliability and the indices of the construction of machines. Real manufacturing environment shows that machinery has often un forecasting malfunction by different causes mostly for automated lines with complicate styling that have numerous mechanical electronic, and electrical units of diverse level of reliability. The theory of reliability states, if industrial management is typically, then each machine can be at more than one conditions: a machine is capable to more than one action, i.e. when it mission to produces specific products; and a machine is unable to suitable work to produces upset products that deemed not acceptable work of a machine and spent time is deemed a time of machine pause. All types of machine random failures necessitate to the idle time of machines and thus lead to repair. All indices of reliability of machines are labelled into twice groups: unique indices that recognize one part of machine failures, index of a reliability that contain several single indication of reliability of an instrument. The theory of reliability gives criterion indices of reliability for reparable machines and one is availability - major indication of reliability of a system that expressed by the formula:

$$A = \frac{T_0}{T_0 + T} \quad (1)$$

Where A – machine availability, T_0 – machine works time; T_i – time that machines do not work include maintenance time.

The availability index is used for machines when random failure outcomes only lead to economic forfeits,

such as loss of the producing a product, etc. Availability is presented by machine failure rate $\lambda = 1/m_w$, or mean time between failures m_w (MTBF), and repairing mean time m_r (MTTR) by the following formula:

$$A = \frac{m_w}{m_w + m_r} = \frac{1}{1 + m_r \lambda} \quad (2)$$

These values vary depending on various parameters as described in the analytical dependencies of the productivity, the design of this system is greatly dependent on the requirement for reliability indices theory with complex design machine. The underlying mechanism are broadly similar to automated lines can be by the other techniques utilizing similar concepts include the numeral of serial, and parallel stations embedded at automated lines, and the number of divisions of automated lines with buffers of varied capacity. The mathematical formula of the different design of machines for the productivity contain technological characters (machining time that depends on processing mode), technical parameters (auxiliary time, capacity of buffers, etc), and constitutional parameters (numeral of serial, parallel stations and numeral of division of automated lines) [7-10]. Also, the mathematical model contains the reliability components, which reported by term of machine idle time could be converted to norm indicator of reliability. Prior test of models of automated lines the outputs shows that reliability composition contains machine "failure rate, mean time to failure, mean time to maintenance, and availability. These indications of reliability in mathematical models of the machine productivity rate can be analytically put together and introduced in the form of the incorporated index of reliability for varies types of automated lines. This index of reliability for automated lines contains composition of lines and capability of buffers, apart from indication of reliability, i.e., the structure one and buffer capacities influence on the reliability level and hence on the productivity rate of automated lines."

II. ANALYTICAL APPROACH

The steps of the analysis process are outline term of the productivity of machines contains all parts of manufacturing processes, i.e. technological innovations that means machining modes, technical that means design and structure of machines, management, maintenance, etc. The mathematical models of productivity of manufacturing machines reappear analytical dependencies of the productivity rate on the plane of sight of the industrial processes. There are models that consider some form of output processes do not relate to the machine reliability. This work considers the model of the machine productivity rate that contains only technical form of the machine and do not have form of

management and repair at prescriptive revise time of machine maintenance. The whole management concepts and skills considerations duty of production process and do not include the correct dependencies on a machine productivity and reliability. Total maintenance concepts and skills regard the machine out of the work, i.e. planned maintenance and duty of machine stopped for revise processes and does not have casual stops of machines. These concepts of management and repair do not have reliability indices of a machine. However, there are included into regard of a machine life time that is general index of machine competence. This approach can be extending the mathematical model of analytical dependency of the productivity and incorporated indication of the machine reliability. The main indication of availability is the incorporated indication of reliability and it is the parameters of approach of the productivity for automated lines. The machine productivity unit has been a measured a number of products produced per some monitoring time. Mostly, a number of products can have dimensions in separated units; weight; length; area; and volume units, etc., which is that, depends on the kind of production processes. Then, the productivity of machines has dimensions' products (parts/time), m/time, m²/time, m³/time, kg/time, etc. In industrial a machine processes have mainly separated production one and the output result of a machine reappeared by the following expression if do not have the idle time due to executive and community troubles [1; 5].

$$Q = \frac{z}{\theta} = \frac{z}{\theta_w + \theta_i} = \frac{1}{\frac{\theta_w}{z} + \frac{\theta_i}{z}} = \frac{1}{T + \sum_{i=1}^n t_{ei}} \quad (3)$$

Whereas z is numeral of machined products per observing time. The monitoring time $\theta = \theta_w + \theta_i$ is introduced as the total of the machine operating time θ_w and idle time due to technique failures of a machine, θ_i . If divide nominator and devisor of Eq (3) on the numeral of products z then ratio $\theta_w/z = T$ is reappeared the one period time for machining of one output. The cycle time $T = t_{mo} + t_a$ is rerecorded the total of machining time, t_{mo} (min/part) of the sum of technique process and the auxiliary time t_a (minute/part) that have time spent on load and reload work-pieces to machining area, clamp a relieve the part, fast motion forward of fixed cutters to work-pieces and back after machining, etc. The idle time is presented by the following expression $\theta_i = m_r \cdot b$, wherever b is the numeral of machine stops. The work time has been presented by the following expression $\theta_w = m \cdot b$, which motif given previously.

The portion of $\frac{\theta_i}{z} = \sum_{i=1}^n t_{ei}$ is whole losses time

referring to once output due to reliability causes of n

machine units (for naivety is used equation of the time losses). The sum of losses time due to reliability causes of instrument units also could be recorded via total of time losses of separate units. Mostly, the machines with complicate design have popular technical units and machines such as control system, transport mechanism with gearing, actuator, etc. that serve all devices. In same case of time losses of same units can be presented by multiplicity of the moderate losses time of unique unit by a numeral of same units in an instrument with complicate structure. This approach can be presented via the following term

$$\sum_{i=1}^n t_{ei} = \frac{\theta_c}{z} + \frac{q\theta_u}{z} \quad (4)$$

Where θ_c is the losses time due to popular mechanization and units, θ_u is the moderate losses time due to unique same mechanizations and units, q is the numeral same mechanisms and units, other parameters given previously.

Replacing a pointed parameter into Eq. (3) and transformations gives the following expression of productivity of a machine

$$Q = \frac{1}{T} * \frac{1}{1 + \left(\sum_{i=1}^n t_{ei} \right) / T} \quad (5)$$

$$= \frac{1}{t_{mo} + t_a} * \frac{1}{1 + \left(\sum_{i=1}^n t_{ei} \right) / (t_{mo} + t_a)} = Q_T A$$

The equation $Q_T = 1/T = 1/(t_{mo} + t_a)$ is a cyclic productivity rate of a machine, i.e. one product per T time or part/min. Then, the availability of a machine after substituting of all pointed parameters and transformation has the following expression.

$$A = \frac{1}{1 + \left(\sum_{i=1}^n t_{ei} \right) / T} = \frac{1}{1 + \frac{\theta_i}{zT}} \quad (6)$$

$$= \frac{1}{1 + \frac{\theta_i}{\theta_w}} = \frac{1}{1 + \frac{m_r b}{mb}} = \frac{1}{1 + \lambda m_r}$$

Where all parameters defined previously.

Eq. (6) is the same Eq. (2) of availability of a machine and contain the failure rate of a machine λ maintenance time m_r due to casual failure of a machine and do not have the order planned revise and maintenance time. In case when the maintenance time, and malfunction time due to administration troubles are inclusive, it is deemed the efficiency of a machine that reflects not only technical troubles, but contains management and service problems of a machine, which is out of this work consideration. Availability is deemed as the incorporated indication of reliability of a machine that is a very necessary index of quality. Substituting Eq. (6) of availability into Eq. (5) gives the following expression of the productivity of a machine

$$Q_t = \frac{1}{t_{mo} + t_a} * \frac{1}{1 + m_r \lambda} \quad (7)$$

Eq. (7) of the machine productivity contains a motif of the machining time t_{mo} , auxiliary time t_a and availability of an instrument. Pointed properties of the productivity of a machine enable to get a new model of the reliability and productivity for manufacturing machines with complicate structures such as automated lines with varied structures.

Availability of the rotor kind automated line is a component of the productivity

In manufacturing area there are numerous kinds of multi station of technical machines with complex design, which productivity is a counted by varies expressions. For example, the rotor kind automated production line (Figure. 1) is a complicate design of the technical machine with its own technological parameters. The daze kind automated output line including to machines of parallel- serial behaviour. The once daze kind un manually instrument is the multi station's device of parallel action. The main variation of the rotor kind automatic device with different designs of the multi station's machine of parallel behaviour is a machining process of a portion shifted at the time on each station. Other variation is the rotor kind automatic machine has once mechanization for loading and reloading of the portions for whole stations. The more than one stations of automatic machine of parallel action of linear structure has the numeral of such mechanisms equivalent to the numeral of parallel stations. The sketch of the multi stations automatic machine of parallel action is introduced in Fig. 2. The sketch of multi stations automatic machine of serial-parallel action is recorded in Fig. 3.

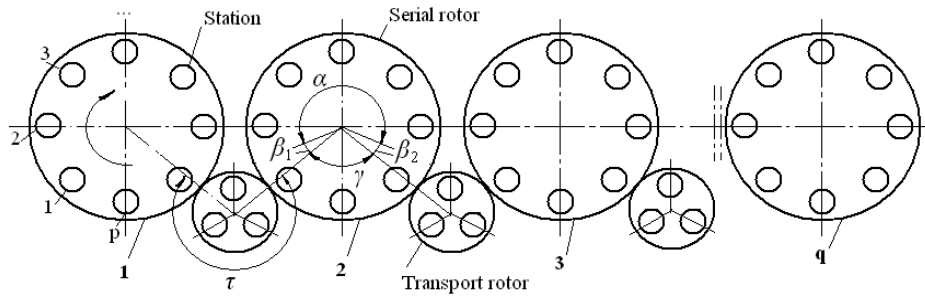


Figure 1: The rotor types line of automated of serial-parallel action with p parallel stations and q serial one of the structure array

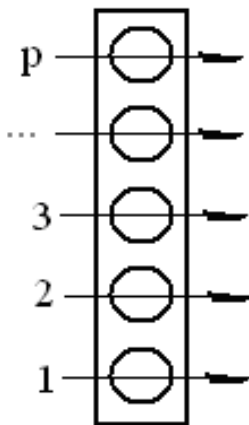


Figure 2: Sketch of a parallel action of the multi station machine with p stations

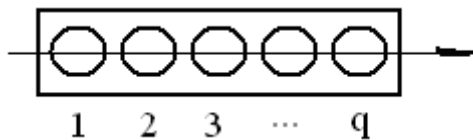


Figure 3: Sketch of the series action of the multi station machine with p stations

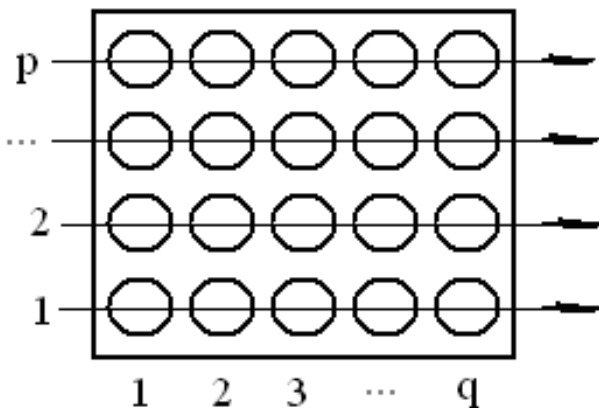


Figure 4: Sketch of a serial-parallel action of the multi station machine with p stations action with q serial and p parallel stations and linear array

Industrial exercise offers the design of the multi station automated line of parallel -serial action with p parallel and q serial stations with linear array is very complicate mission due to many limitations. Empirically, Technicians produce that automated lines with more than one parallel fluxes embedded in one arrangement and very infrequent three parallel flows for the stumpy automated lines. The serial - parallel action design of automated lines is carried out by twice types of automated production line templates. First kind of automated output line of serial-parallel activity have linear array and used for processes of extended cycle time like machining of housing portions, shafts of complex design. Second type of experiment that involved asking a respondent a daze-kind array (Figure. 1) with q serial and p parallel terminals, in practice, it can be convenient and compact the point of shows a design, this could play a supportive role in the maintenance. Such automatic machines this ensures that the mechanism is as clear and efficient as possible to find innumerable applications in many different areas such as pressing, coining, liquid filling to bottles, etc. These values vary depending on various parameters as described in the analytical models. The validation results confirm that the methods produce values within appropriate tolerance levels of a daze-kind automated line has following expression in (Fig. 1). This is argued to be a strength of this piece of work through the revolution of the rotor work, work-pieces are implemented. In zone β_1 , a work-piece is loaded and a tool model a work-piece quickly. In zone α performance of this new technology is still a matter of debate process (stamping, sketching, installing, etc.). In zone β_2 , a tool of cutting is replaced and a processed product released. In zone γ , a cutting tool is tested and washed out. Zone α performed the machining operation (t_{mo}), whereas zones β_1 and β_2 performed auxiliary movements (t_a) [8-9]. All rotary automated line leads to stop at any failure of parallel or serial stations due to all mechanisms. A system reliability analysis tools is Reliability Block Diagram (RBD), Fault Tree Analysis (FTA), Failure Mode and Effect Analysis (FMEA) [1-5]. The rotor kind automated production line could be presented a graphical RBD for a system of common components (control unit, actuator, etc), transport, parallel, and serial components. The work station is stopped, whereas, at least one of the

components is flopped (Fig. 2). Failure of one station leads to stop all serial-parallel stations, the performance steadily increases and decrease idle time of stations and reduction the productivity respectively. However, the reliability block diagram does not deem the motif of productive unit. This theory deems reliability approach of the electronically system by typical serial, parallel and combined models. whereas accepted a principle for serial component: system is stopped if at least one of the motif is flopped, and in parallel systems: system is working if at least one of the components is working. The regulation of the reliability theory could not be applied for manufacturing machines with complicate design, which concept of work are very different. Empirically in area of industrial machines with complicate system, which is supposed the reliability in moderate of every device or station in the factory is the similar. In status of the daze-kind automated line passable once norm for parallel and serial stations (devices): A system is stopped if at least once of the terminals is flopped that will be serial or parallel one. The flopped of popular mechanizations of instruments with complicate design is deemed disconnect. The result of this norm is growing the losses time confer to the Equation. (4) has the following expression

$$qp_s \sum_{i=1}^n t_{ei} + t_c = \frac{qp_s \theta_s}{z} + \frac{\theta_c}{z} \quad (8)$$

Where θ_s – idle time of one section station, θ_c – malfunction time of popular mechanisms, p_s is numeral of parallel stations, q is numeral of serial stations, different propertied given previously. Mannerly analytical term of the productivity of the daze-kind automatic streak of serial – parallel activity has been reported at the previous studies [9]. Formula of productivity of the daze-kind automated streak has expression

$$Q_{pq} = \frac{p}{\left(\frac{t_{mo}}{q} + t_a\right) \left(2 + \frac{p_\gamma + p_t - 1}{p_s - p_\gamma}\right) + (t_s + t_t)p_s q + t_c} \quad (9)$$

Wherever p - the numeral of output (every terminal perform once output, i.e. numeral of outputs is similar to a numeral of stations $p = p_s$), q - A numeral of serial terminals, t_{mo} the working time of the sum technique process, t_a – the auxiliary time, t_c – the losses time due to reliability of popular mechanizations (actuator, control unit, etc), t_s – the time losses due to reliability of station's mechanizations, t_t – the time losses causes reliability of carry mechanism, p_t - the numeral of stations that located on the transport angle τ of the transport rotor; p_γ - the number of stations that located on the idle angle γ of the rotor machine (Figure. 1), other motif reported previously.

The Equation. (9) A construction of daze-kind automated has been re suggested, i.e. the numeral serial (q) and parallel stations (p_s). A numeral of parallel stations (p_γ) does not involve at machining process due to design properties of the rotor machine, the number of parallel stations (p_t) involve at relocating process of potions. Eq. (9) contain parameters of the technological process (t_{mo}), design (t_a), and Undertaking such an analysis would therefore be technically difficult due to the reliability and construction one (t_c, t_s).

The expression of Eq. (9)

$$\left(\frac{t_{mo}}{q} + t_a\right) \left(2 + \frac{p_\gamma + p_t - 1}{p - p_\gamma}\right) = T \left(2 + \frac{p_\gamma + p_t - 1}{p - p_\gamma}\right) = Td$$

Is the operating time of p output parts, when $d = 2 + \frac{p_\gamma + p_t - 1}{p - p_\gamma}$ is the cycle time deposition factor.

Analysis display that Eq. (9) depend on from the periodic productivity, deposition factor and from availability of a rotor kind automated line. Availability is suggested after transformation Eq. (9) and exchanging of the periodic time of the automated line by the following expression,

$$Q_{pq} = \frac{p}{Td} \left(\frac{1}{1 + \frac{(t_s + t_t)pq + t_c}{Td}} \right) = Q_{Td}^A \quad (10)$$

Wherever the first character of Equation. (10) is the detached periodic productivity of daze-kind automated path.

$$Q_{Td} = \frac{p}{T \left(2 + \frac{p_\gamma + p_t - 1}{p - p_\gamma}\right)} \quad (11)$$

The 2nd character of Eq. (9) is availability of the daze-kind automated path

$$A = \frac{1}{1 + \left[\frac{\{(t_s + t_t)pq + t_c\}}{T \left(2 + \frac{p_\gamma + p_t - 1}{p - p_\gamma}\right)} \right]} = \frac{1}{1 + \left[\frac{\{(t_s + t_t)pq + t_c\}}{Td} \right]} \quad (12)$$

For practical reasons, we would like to include availability of an automated path time losses due to mechanical causes, (t_c, t_s, t_t), its construction parameters (q, p). Availability of the rotor path is integrated

indication of reliability of the automated path, and shows a right result then other same indices of reliability that suggested at popular formulas [3-5]. However, which is obvious that these limitations reflect inadequacy of the data availability of the all automated system, whereas, will be proofed later. The time productivity losses due to mechanical causes, (t_c, t_s, t_t) could be suggested via the constant indications of a reliability of the devices. The losses time of the daze kind automated path of a mechanical causes accounted by the following expression.

$$(t_s + t_c)pq + t_c = pq \left(\frac{\theta_s}{z} + \frac{\theta_t}{z} \right) + \frac{\theta_c}{z} \quad (13)$$

Where θ_c - the idle time of a popular mechanisms of a rotor device, θ_s - the idle time of a working rotor machine with p stations, θ_t - the idle time of a convey rotor, $z = \theta_w/(Td)$ - is the numeral of machined products created per same monitoring time of work of a rotor-kind automated path.

The solution proposed here is based on this mechanism and devices of an automated line due to the idle times causes is expressed also by indices of reliability, $\theta_i = m_r b$, where m_r - mean time to maintenance, b - the numeral of shutdowns. These value was calculated for each of as described in equation $\theta_w = m_w b = b/\lambda$, and λ - a machine failure rate. In manufacturing area, each parameter was recorded and accepted by average magnitude 2-3 minutes is a mean values used for analysis a means time to reform m_r of random failure of machine units. The availability mathematical analytical model of the daze kind automated line could contain λ_c , λ_s and λ_t that is the flopped rates for popular mechanization, the daze stations and convey to rotor respectively. After replacing of reliability indication recorded previously and transformation, availability of the daze kind automated path shall have the next expression

$$A = \frac{1}{1 + \left[\left\{ pq \left(\frac{\theta_s}{\theta_w/(Td)} + \frac{\theta_t}{\theta_w/(Td)} \right) + \frac{\theta_c}{\theta_w/(Td)} \right\} / Td \right]} = \frac{1}{1 + \left[\left\{ pq \left(\frac{m_r b_s \lambda_s Td}{b_s} + \frac{m_r b_t \lambda_t Td}{b_t} \right) + \frac{m_r b_c \lambda_c Td}{b_c} \right\} / Td \right]} \quad (14)$$

$$= \frac{1}{1 + m_r [pq(\lambda_s + \lambda_t) + \lambda_c]}$$

Where all parameters given previously.

These methods could be extended to other types of problems in the area availability of the daze kind automated line (Eq. (14)) includes standard indication of

reliability of technicality (m_r, λ_i) . After substituting Eq. (14) into Eq. (10), the technical parameters and integrated index and reliability of the line productivity of the daze kind automated line will be report in the mathematical model. This integrated indication includes the average time to maintenance (m_r) , machines failure rates (λ_i) , and construction of the daze kind automated line (p, q) .

$$Q_{pq} = \frac{p}{\left(\frac{t_{mo}}{q} + t_a \right) \left(2 + \frac{p\gamma + p_t - 1}{p - p\gamma} \right)} \quad (15)$$

$$* \frac{1}{1 + m_r [pq(\lambda_s + \lambda_t) + \lambda_c]}$$

It is easy to calculate a necessary plane of reliability of the daze-kind automated line due to the ordered productivity or vice versa. Whereas a value of reliability indices of the automated streak motif is recognized.

The parallel, serial actions of automated lines and linear array for availability component of the productivity

The mathematical model in Eq. (15) has been transformed according to a structure of the automated line of parallel -serial action and linear arrangement of a productivity of the daze-kind automated streak. The sketch of an automated line is presented in Fig. 4. Which is can be presented by the following properties: finishing operations of the parts, which are whole stations has been started to work at one time and then the products are imparted by the linear structure of transport mechanization to the next stations.

The equation (15) of the productivity of the rotor type automated line should be omitted the contains of the period time distance factor d , then the equation of serial -parallel action for the productivity with availability of automated streaks and linear array could have the next expression

$$Q_{pq} = \frac{p}{\left(\frac{t_{mo}}{q} + t_a \right)} * \frac{1}{1 + m_r [pq(\lambda_s + \lambda_t) + \lambda_c]} \quad (16)$$

The linear array of the automated lines of serial action (Figure. 3), $(p = 1)$ is a factor of parallel flow, which is the model of the productivity with availability of could have the next expression

$$Q_{pq} = \frac{1}{\left(\frac{t_{mo}}{q} + t_a \right)} * \frac{1}{1 + m_r [q(\lambda_s + \lambda_t) + \lambda_c]} \quad (17)$$

The p and the numeral of serial station $q = 1$ for the automated streaks of parallel action and linear configuration while numeral of parallel stations (Fig. 2) the model of the productivity with availability shall have the next equation

$$Q_{pq} = \frac{p}{(t_{mo} + t_a)} * \frac{1}{1 + m_r [p(\lambda_s + \lambda_t) + \lambda_c]} \quad (18)$$

After derived and simplifications of Eq (15) will get the Eqs. (16) – (18) according to constructional properties of those type automated lines that reported previously.

The serial section-based automated line is a motif of availability and productivity

The previous studies on automated lines, in area of manufacturing engineering specially in metal cutting industry, introduced numerous models to imitate line balancing by time and reliability, layout analyze, production timing, etc. [9 -15]. The reliability and productivity rate of automated streak could be amended if separate the automated streaks of serial action into some divisions and placing buffers between them that enables slide in a line of idle time and in turn results in raised of output [7-10]. In common, an automated streak is divided

on divisions with equivalent reliability and equivalent time losses of divisions may have variation numeral of stations. Empirically it is potential to structure such streaks while a plane of reliability of stations is recognized. Some differences of reliability stations shall have not a huge effect on an output of an automated streak. Refer to this configuration, whether one station flopped, the entire line couldn't pause except for the section with the flopped station. which is because the different divisions shall keep operation by turn on or exhausting the buffers existed before/after a flopped section. The amplitude of buffers could be equipping sufficient supply to the automated streak until flopped station is set. Such approach enables reduce in idle time and rise in automated streak of output. At the next, the result of output of the section based automated streak can be accounted by the productivity of one division. In case when reliability of sections has some earnest variation that are quite rare, the trouble of output result of automated line could be fixed by probability mathematical approach of work time of divisions. The sketch of the automatic streak of serial action that is discordant into n divisions with embedded buffers B is reported in Figure. 4.

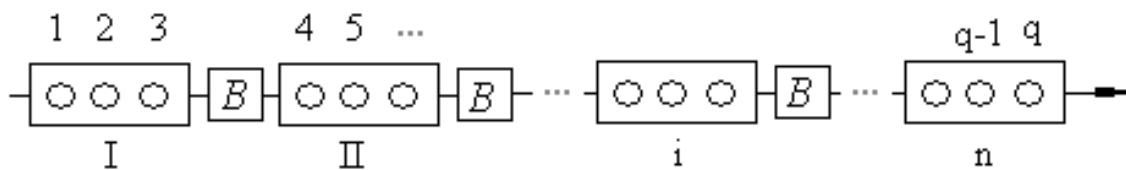


Figure 5: Sketch of a serial division-based automated output line with q stations, segmented on n divisions with B buffers

The really of production ambience the buffer system capacity is finite by numerous properties like its cost, some area of technical properties. In fact, buffer system can repay only some partition of the idle time of an automated line and every partition shall have not only its possess idle time, but also un recover idle time due to the limited capacity of the buffer system located between divisions.

A schematic performance of RBD for the serial section-based automated output line can be considered as system of serial divisions with terminals, and buffers, while a section is flopped if at least one of the stations in this section is flopped (Fig.5). It means that any failure of one station of the automated line leads to halt only unique section, however have not all automated line. Other divisions operation until filling or exhaust inter-sectional buffers then could be flopped next door divisions that growing idle time of sections and reduce output of an automated line. This construction of the section-based automated is not looked by the theory of reliability, which stated: series system is flopped if at least one of the parameters is flopped. In such situation, it is needful to

expanded the analytical equation of the availability for the serial section- based automated line. A modelling approach of the time losses of the divisions due to the bounded buffer capacity derived and reported in form of the factor of the section time losses growth [10]. On the basis of this coefficient, a new refined model of the productivity of a terminal-based automated line with the bounded buffer capacity developed later. The mathematical approach contains a new properties of a time losses due to reliability and capacity of the buffer and the following equation.

$$Q = \frac{1}{\frac{t_m}{q} + t_a + \frac{q}{n} t_s \left[1 + \frac{2\Delta(1 - \Delta^{n-1})}{1 - \Delta} \right] + t_b + t_c} \quad (19)$$

Where, n is a numeral of divisions in the line; $W = 1 + \frac{2\Delta(1 - \Delta^{n-1})}{1 - \Delta}$ is the factor of increase of time

losses due to unrequited idle time by causes of the exclusive buffer gage; Δ is the moderate a coefficient of inter-terminals order of time losses from other divisions due to bounded gage of the buffers; t_b - the time loss of a buffer; different parameters are the same as for the automated lines that explained previously.

The Eq. (19) of the section productivity rate is based automated production line has contains

$$t_t = \frac{q}{n} t_s \left[1 + \frac{2\Delta(1 - \Delta^{n-1})}{1 - \Delta} \right] + t_b + t_c \quad \text{that is the}$$

gross time losses according to mechanical causes of the automated line that be inverted its reliability and construction. After substituting and transformation, Eq. (19) is introduced by following equations

$$Q = \frac{1}{T} \left(\frac{1}{1 + \left[\frac{q}{n} t_s \left[1 + \frac{2\Delta(1 - \Delta^{n-1})}{1 - \Delta} \right] + t_b + t_c \right] / T} \right) = Q_T A \quad (20)$$

Where,

$$A = \frac{1}{1 + \left\{ \frac{q}{n} t_s \left[1 + \frac{2\Delta(1 - \Delta^{n-1})}{1 - \Delta} \right] + t_b + t_c \right\} / T} \quad (21)$$

The availability serial action of automated line of a section-based of A contains the reliability coefficients t_s , t_c , t_b , structural coefficients (q , n) and mechanical coefficients (Δ) of buffers of accounted gage.

The reliability coefficient, as the time absences of a station according to mechanical causes of the automated line is interpretative same as reported previously for Eqs. (13) and (14)

$$(q/n)Wt_s + t_b + t_c = m_r T [(q/n)W\lambda_s + \lambda_b + \lambda_c].$$

The process of replacing and transformation of Eq. (21) is same as to the process for the introducing of availability for the other kind of automated lines, Eqs. (15-18). At last, availability of the section founded automated line shall have a next expression

$$A = \frac{1}{1 + m_r \left\{ \frac{q\lambda_c}{n} \left[1 + \frac{2\Delta(1 - \Delta^{n-1})}{1 - \Delta} \right] + \lambda_b + \lambda_c \right\}} \quad (22)$$

The availability of section capacity is founded the automated line with buffers has been fixed, Eq. (22) include indication of reliability (m_r , λ_i), coefficients of construction of automated line (q , n), and mechanical coefficient the capacity of the buffer Δ . whereas,

availability A introduce the integrated index of reliability of the section based automated line. It means there is interrelationship between technical coefficients that have reflect on the availability section-based automated line and with the machine reliability indices. The productivity section-based automated line with buffers of founded capacity is introduced via next formula that includes whole technical parameters of the line and its availability

$$Q = \frac{1}{\frac{t_m}{q} + t_a} \left(\frac{1}{1 + m_r \left\{ \frac{q\lambda_s}{n} \left[1 + \frac{2\Delta(1 - \Delta^{n-1})}{1 - \Delta} \right] + \lambda_b + \lambda_c \right\}} \right) \quad (23)$$

Eq. (23) of the output result of section based availability automated line, its enables to solving of engineering troubles same the necessary plane of reliability of a machine according to order productivity rate or if a level of reliability of a machine is recognized, it is easy to account its productivity.

III. AN INDUSTRIAL CASE STUDY

In areas of industrial , there are standard facts of availability of machines located within 80% - 85%, i.e. $A = 0.8 - 0.85$, and mean time repair $m_r = 2 - 3$ min. These normative data also enable to solve engineering problems that concern the level of the availability, and single indices of reliability of a machine, structural and technical parameters, and the productivity rate of a machine.

1. The rotor type automated production line

Assume that the rotor kind automated production line could be designed with differences. It have a next data: $q = 4; 5; 6$ - the number of machining stations of the rotor line; $p = 10; 12; 14$ - the numeral of parallel stations of mechanization rotor; $p_\gamma = 4$ - the numeral of idle stations of the machining rotor, $p_t = 2$ - the number of transport stations in the transport rotor; $t_{mo} = 1$ min/part - the mechanization time, $t_a = 0.1$ min/part - the auxiliary time, $m_r = 3$ min - the average time to repair of the daze kind of automated line, $\lambda_s = \lambda * 10^{-4}$ - the flopped rate of a station of the automated line, $\lambda_c = \lambda_t = \lambda * 10^{-8}$ - the flopped rate of public mechanization, and transport rotor is so small, and can be neglected.

The Eq. (8) and Eq. (9) have been substituting this data and calculating, the output of availability of the daze kind of automated line and its productivity against the failure rate one is introduced in Fig. 3. The sketch displays that increasing the flopped rate of the automated line reduces the value of availability of the rotor type automated line. Rising the numeral of parallel and numeral of serial stations of the automated line related to the value of availability of the automated line, increase numeral of stations less availability.

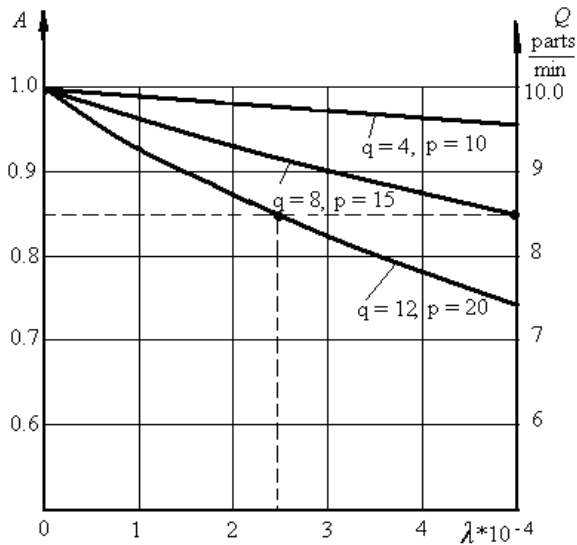


Figure 6: Output result of the rotor type automated line together q and p parallel stations versus the grow of the flopped rate λ of the automated line

If availability approved is $A = 0.85$ then:

- The automated line with $q = 12$ serial and $p = 20$ parallel stations could have the flopped rate $\lambda \leq 2.4.0 \cdot 10^{-4}$ failures/min,
- The automated line with $q = 8$ serial and $p = 15$ parallel stations could have the flopped rate $\lambda \leq 5.0 \cdot 10^{-3}$ failures /min.

These two structural variants of the rotor type automated line gives the technical productivity rate $Q_t = 8.5$ parts/min.

The automated line with $q = 4$ serial and $p = 10$ parallel stations has too small value of flopped rate and has high reliability, and gives higher rate of productivity. Which construction of the line is preferable should be estimated by criterion of economic efficiency. Growing the reliability and change the construction of the automated line leads to change of the cost one.

Generally, the growing of the numeral of parallel and reducing of the numeral of serial stations of the rotor type automated line do not relate relatively on the output of a rotor kind automated line [6:10]. thence, the variation of the numeral of parallel or serial stations of the automated line could be estimated according to a needful plane of the productivity and then should be select the value of availability as integrated indication of reliability of the automated line. Finally, labors of an automated line should estimate the technical parameters one by norm of economical efficiency.

2. The automated line based on serial section together with a capacity buffers founded.

Assumption that the section based automated line of production for embedded buffers have next data: q - numeral of machining stations, n - numeral of divisions, and $t_m = 1$ min/part - the machining time, $t_a = 0.3$ min/part - the auxiliary time, $\Delta = 0.1$ - the moderate coefficient of

the inter-sectional imposition of productivity losses, $m_r = 3$ min - moderate time repair of a machine or station; λ_b and λ_c - the failure rate of a buffer and common mechanisms is small and can be ignored. After replacing these data into Equations (19 and 22), the output of the productivity of the automated line and the availability as a function of the flopped rate is reported in Figure.7.

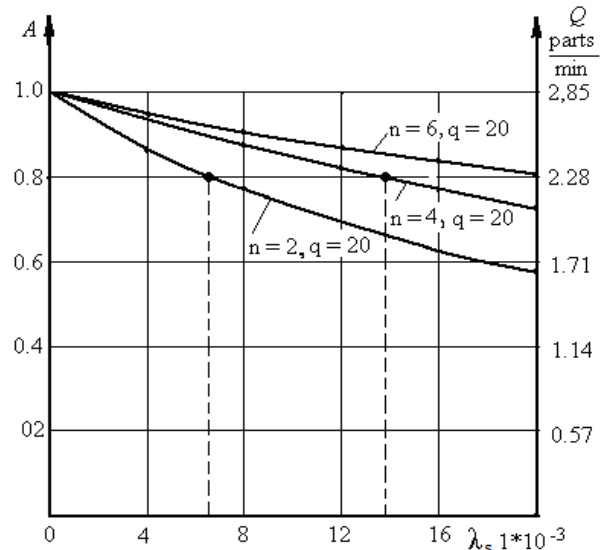


Figure 7: Output result of availability of the section-based automated line with q stations and section on n divisions versus the increase of the line failure rate λ

The sketch displays that growing the line flopped rate reduces the magnitude of availability and output of automated line. Growing the numeral of divisions and numeral of stations in the automated line grows the value of availability and also increased the productivity rate of the automated line. If availability accepted is $A = 0.8$ then:

- The automated line with $n = 2$ divisions and $q = 20$ stations could have failure rate
- $\lambda \leq 6.5 \cdot 10^{-3}$ failures/min,
- The automated line with $n = 4$ divisions and $q = 20$ stations could have flopped rate
- $\lambda \leq 13.7 \cdot 10^{-3}$ failures/min,
- The automated line with $n = 6$ divisions and $q = 20$ stations could have flopped rate
- $\lambda \leq 20 \cdot 10^{-3}$ failures/min,

Thence, increasing the numeral of divisions into the automated line can recompense the low level of its reliability. The increasing of the number of divisions into the automated line does not relate relatively the increase of availability of the automated line.

IV. DISCUSSION OF RESULTS

The mathematical approach of availability of the exemplary automated lines with complicate designs has been derived, which is show that availability depends on:

- Criterion indices of reliability of techniques;
- Character of construction and layout of the automated line, i.e., on the numeral of serial, and parallel stations, and on the numeral of divisions of the automated lines;
- Mechanical properties like the capacity of the buffer.

The availability of the automated line equations enabled to calculate the magnitude of productivity a duty of the reliability indices, the technical and technological characters one. Automated production lines equations have been introduced tested on the section-based serial and rotor type. The necessary tolerances result of calculations could be enable to define of availability and different technical characters for of the section-based serial and rotor type automated production lines respectively as function of productivity of the automated lines.

V. CONCLUSION

The output result of the mathematical model is product, which is of any complicate manufacturing machine related to the technological process, reliability of units and a structure of this machine. Analytical study of the reflect to reliability, the parameters such as technical and technological on the machine result introduce that there is good mathematical dependency of the productivity rate and availability of the manufacturing machines.

The analytical equations in this work has been contribute to the development of the availability of the typical of the layout of industrial automated lines. This main indication of the reliability of the industrial machines with hard design depends not only on norm of indices of reliability of mechanisms, but also reflect on motif of construction design and technical data of the complicate manufacturing machines.

The equations have been reported of availability for the typical designs of automated production lines give the output based on the index of reliability of mechanisms and machines and on the construction and technical motif of units of the automated lines.

The modelling equations the output of automated lines of availability and productivity will be useful in, defining a construction, estimating the numeral of parallel and serial stations and, also the capacity of buffers according to the needful plane of the reliability of hard design industrial machines. Engineers, labours of automated lines could be use the results of model has been derived analytical in the automated line design.

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