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Comparative Integrated Manufacturing Efficiency in Production Engineering

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Abstract

At present a plurality of manufacturing methods, different manufacturing processes and manufacturing equipment are known in order to produce and customize work pieces and products. A new systematic approaches for the analysis and evaluation of manufacturing methods bases on the energy-information model as a conceptual approach to the comparative integrated manufacturing efficiency in production engineering. The integrated manufacturing efficiency is equal to the product of the efficiencies of matter, energy and information. The Comparative Integral Manufacturing Efficiency is the product of Quality rate, Effectiveness, Availability, devided by the product of (used Energy, used material, Emission ratio). A case study compares additive and removal process efficiencies for the production of a hollow cylinder. Proposed method for comparative integrated manufacturing efficiency will offer resource-efficient strategies for the creation and optimization of processes and technology applications.

Keywords: manufacturing; efficiency; technological process

1. Introduction

Material production, as a system, consists of two elements: the object with its inherent properties and technology, with its inherent parameters and characteristics. Therefore, the development of such a system is possible (in essence) in two ways: -the improvement and creation of a new object and its properties; -improvement and the creation of new production technologies. It is obvious that the selection of the first direction of development is less efficient and competitive in the long term (because the new object and its properties (obvious and foreseeable set) are rather quickly reproduced with the help of existing technologies). The selection of the second direction is more efficient and competitive (because its reproduction is less obvious and achievable in the short term due to a number of parameters and characteristics, which form and define the conditions of development of new technology). Of course, if we analyse the system, there is a third direction (this direction requires significantly more resources, which are needed for development). Third direction is a combination of above mentioned two directions. Nevertheless, when priority is selected (taking into account the limitedness of resources), preference is given to the development of the second direction.

Currently, a plurality of methods for machining and forming parts and products, processes and equipment is known for their implementation. Modern tendencies towards improvements in productivity, accuracy, reliability, flexibility, efficiency and effectiveness influence both the production and processing equipment and machinery systems. In order to influence the production object, the development of new systematic methods of analysis is required, which applies for the implementation of these objectives and the development of new machine structures, and which can fully implement the various physical processes.

That is why a deeper and more comprehensive structural and systematic description, which can analyse technologies

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and equipment, and the analysis of system elements, their connections and relationshipsare required.

From this point of view, the most comprehensive and systematic model, which can analyse technology and machines and equipment, which are based on this technology, was offered by Russian scientist I. Artobolevsky: "The machine is a device that performs mechanical movements to transform matter, energy and information" ie based system put elements (matter, energy and information) without specifying the type of relationship between them. ***So, the basis of this system are elements (matter, energy and information); the type of their interactions is not defined.***

In German standard DIN 8580-2003-09 (Fertigungsverfahren - Begriffe, Einteilung) the following classification of technological processes (technologies) is given: 1 – Primary Shaping and/or Original Forming (blanking operations : mainly, casting operations), 2 – Forming, 3 – Separating (3.1- cutting with geometrically defined cutting edge, 3.2 – abrasive machininga, 3.3 – separating and chopping operations), 4 – Joining, 5 – Coating and Finishing, 6 –change of material properties.

So the basis of the system is architecture of material connections, which is viewed as a system:

1 – connections, which create new material object;

2 – preserving connections;

3 – destroying connections;

4,5 – increasing connections;

6 – connections, which change the properties of material internal connections.

In other words, the basis of this system are types of internal connections and their interactions; atomic or molecular structure of the matter substance are adopted as elements.

Unit manufacturing processes are classified into five families of physical processes [1]:

1 – *Mass-change processes* involve material removed or added by mechanical, electrical, or chemical means. These include plating, machining, grinding, as well as nontraditional removal processes such as electro-discharge and electro-chemical machining;

2 – *Phase-change processes* involve producing a solid part from material originally in the liquid or vapor phase. These include casting of metals, infiltration of composites, and injection molding of polymers;

3 – *Structure-change processes* involve altering the microstructure of a workpiece, either throughout is bulk or in a localised area, such as ist surface. These include heat treatment and surface hardening processes;

4 – *Deformation processes* involve altering the shape of a solid workpiece without changing its mass or composition. These include processes of rolling and forging, and sheet-forming processes of deep drawing and ironing;

5 – *Consolidaton processes* involve combining materials such as particles, filaments, or solid sections to form a part or component. These involve powder metallurgy, ceramic molding, and polymer-matrix composite pressing. Joining processes, such as welding and brazing, also belong to this process family.

So, manufacturing process as a system is defined as a type of physical changes (only elements are analysed, not their connections).

2. Integrated manufacturing efficiency approach

Architecture of technological process, physical processes and part properties interactions is shown in Fig.1.

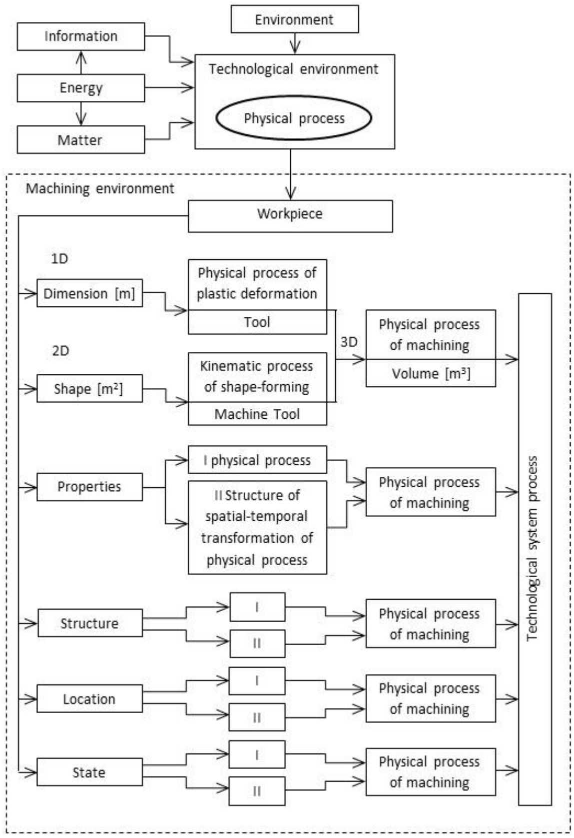

Fig.1. Architecture of technological process, physical processes and part properties interactions

System elements, ensuring the forming of part dimension (physical process, implemented by the tool) and the forming of part surfaces (physical process of surface forming, implemented by operating elements of the machine), are highlighted here. Other characteristics and parameters, that describe the information image of the part, are formed by other methods of processing in accordance with the technological image of the part [7]. Technological process is performed through the manufacturing equipment with use of material, energy, information. The result of the technological process is the product, which shall meet the customer's expectations. Consequently, the manufacturing process consists of two parts: a set of items of physical processes I (the physical process of plastic deformation, which defines the size, is shown) and its corresponding set of structures of spatial temporal transformation II of the physical process (kinematic process of forming, which defines the desired shape of the part, is shown). In order to achieve the desired properties of the part (such as hardness) other physical processes are needed (other than the plastic deformation operations) and their spatial temporal transformation, the structure of which is given in [7]. In this case under the production process we understand the process of interrelated conversion of matter, energy and information.

When the production process is carried out, properties and/or conditions and/or structures of input matter M are being changed (under the influence of input energy E and in accordance with input information I). Matter, energy and information may or may not coincide with each other in terms of input time, conversion time and interaction time.The production process is complete if only the information equality is reached. This equality is contained in material object P (product). The information is visualized in form of drawing P` (information model of material object). Discrepancy (deviation) of information about properties of the object, which is contained in material object P and is similar to the information about object properties, contained in the drawing P`, characterizes accuracy (quality) of the production process. The production process property to ensure production of the given batch quantity and to save in time the information about product properties, which is contained in material product and its drawing, characterizes the reliability of the production process. Depending on the form of energy, performing a change of state, structure, properties of the material, quantity and method of information transfer different production processes are distinguished: edge cutting machining (machining process), forming operation, casting, welding, heat treatment, bending, etc.

Information about the quantitative, qualitative, geometric parameters, form, structure, state, position, and their properties, contained in the description or drawing, is **the information image of the product** [7]. Information about geometric parameters, form and properties of the product, which are contained in the description or drawing, is the **geometric image of the product**. Information about the sequence of the conversion of matter, energy and information, contained in the documents, that define the model of consistent achievement of equality of the information (in the broad sense) in the material object and its technological image, is **the technological image of the product**. Types, forms, methods and processes of energy conversion, which form a compliance of part to its information image, is **the energy image of the product**. The amount of energy, required for the formation of the same part property in accordance with its information image, is the characteristic of **energy content of the image** [2,3,8,9]. Changes and mutual relationships of the properties of respective images characterize and define their quality. These quality parameters include parameters of accuracy, productivity, reliability, energy-efficiency, materials consumption, etc.

Changes and mutual relationships of the properties of respective images characterize and define their qualitative and quantitative parameters and characteristics. The indicators include the accuracy, productivity, reliability, energy-efficiency, materials consumption, etc.

For example, the *accuracy of the production process* depends on the level of compliance or degree of approximation of the actual image parameter (information parameter, geometric parameter, technological parameter) to their nominal, specified or ideal value. That is why it is needed to distinguish following types of accuracy: *product accuracy*, *physical process accuracy*, *really achievable accuracy*, *technological accuracy*, *system accuracy*, *structural accuracy*, *effective accuracy*, etc.

In other words, accuracy (as a system characteristic) is also a result of interactions between different elements and their connections (if we use systematic approach). In the same time, these interactions define new system (as it was mentioned above). The main characteristic of this new system is accuracy.

Productivity describes the rate of technological image properties achieving of information image properties (per unit of used resource) or number of technological image representations per unit of time, etc. That is why it is also needed to distinguish following types of productivity (using the system approach): *physical process productivity*, *technological productivity*, *achievable productivity*, *real productivity*, *effective productivity*, *energetic productivity*, *system productivity*, *structural productivity*, etc.

In other words, productivity (as a system characteristic) is also a result of interactions between different elements and their connections (if we use systematic approach). In the same time, these interactions define new system (as it was mentioned above). The main characteristic of this new system is productivity.

A large number of established and emerging physical and technological processes and equipment require to develop a method of comparable evaluation to justify the selection and / or the limits of their effective application. This paper targets a comparison of systems and technologies in production engineering. Changes and relationship properties of the corresponding images characterizes and defines their properties. A common approach to the assessment of the effectiveness of processes, equipment and productions in terms of community assessment methodology, allows us to consider them as energy-model, in which the conversion of all shapes and types of energy, matter and information. This approach allows us to consider the concept of efficiency as the relative efficiency of the collection of all kinds of conversion elements of the system. Then, using the analogy of building structures in energy efficiency, information efficiency, productivity, accuracy, obtained a general (integral) expression assess the Integral Manufacturing Efficiency of new physical processes and production technologies, which are based on new physical phenomena and processes of transformation of matter, energy and information.

Characteristics	Parameter	State of the art
Manufacturing process	Material Removal Volume to Energy Consumption	DIN 8580, CIRP EREE
Quality rate	Proper Quantity to the Produced Quantity	ISO 22400
Effectiveness	Production Time per Unit * Produced Quantity to Main Usage Time	ISO 22400
Availability	Main Usage Time to the Planned Allocation Time	ISO 22400
Energy ratio	(Energy Bought plus Energy Internally Produced) to the Value Added	ISO 22400
Ratio of used material	Total Amount of Material Used to the Value Added	ISO 22400
Emission ratio	Fossil CO_2 Emissions to the Value Added	ISO 22400; ISO 14955

Table 1: Elements for Comparative Integrated Manufacturing Efficiency

Then **Efficiency** is the extent of the use of any resource; **Productivity** is the rate of change of properties, conditions, structure of matter; the **Accuracy** of processes, equipment and productions determined by the level of compliance or degree of approximation of the amount of information about the real properties, parameters and characteristics of the product (object, product or part) to the nominal amount of information, or given ideal [4].

Therefore, the volume ratio (of energy, power, information, time, etc.) at the output and the input E_{out} / E_{inp} is an estimate of the efficiency E_e [10,11]. The numerator E_{inp} characterizes the resource really used in a process of technological machine, production system. The numerator E_{out} is useful for the theoretical possible maximum value of the resource due to the physical phenomena of the process, equipment or system. Thus, in all cases the use of the resource value of the resource we have: the ideal (nominal or theoretical) and the real (actual). Then we can write the expression for the evaluation of performance indicators:

$$E_e = \frac{E_{out}}{E_{inp}} \quad \text{or} \quad E_e = \frac{E^f_{out}}{E^f_{out} + E^{ch}_{out}} \quad (1)$$

where E^f - the physical processes of the using resource ;
E^{ch} - processes that ensure the use of the resource and its losses.

In general form, when used several types and forms of resources, we get:

$$E_e = \frac{\sum E^f_{out}}{\sum E^f_{out} + \sum E^{ch}_{out}} \quad (2)$$

Comparison of processes, equipment and productions made on the basis of their relationship:

$$U_e = \frac{E^1_e}{E^2_e}$$

The expression efficiency in the form of (2) is a universal method of assessment, therefore also applicable to the analysis of all types of processes, production machines and production systems. It includes the conversion of several types of resources, such as several forms of energy in hybrid machines, considering the energy which is actually spent in the process itself and the energy for the production machine. This method makes it possible to compare the degree of perfection of the processes, due to the possibility of taking into account all types of losses as in the transfer of energy, matter and information from the source to the transforming mechanisms and devices, as well as the transformation in them.

The overall efficiency of the system is equal to the product of the efficiencies of components:

$$E_{te} = \prod_{q=1}^{k} E^k_e \quad (3)$$

The integral efficiency will be equal to the product of the efficiencies of matter E^m_e, energy E^e_e and information E^{in}_e

$$E^i_e = E^m_e E^e_e E^{in}_e \quad (4)$$

Consequently, the comparative effectiveness U^{ci}_e of the two (1 and 2) processes, equipment and productions will be equal to:

$$U^{ci}_e = \frac{(E^m_e E^e_e E^{in}_e)^1}{(E^m_e E^e_e E^{in}_e)^2} = U^{cm}_e U^{cie}_e U^{cin}_e = \frac{(E^m_e)^1}{(E^m_e)^2} \frac{(E^e_e)^1}{(E^e_e)^2} \frac{(E^{in}_e)^1}{(E^{in}_e)^2} \quad (5)$$

Where E^m_e - indicator productivity; E^e_e - indicator energy efficiency; E^{in}_e - indicator accuracy.

Then, if we use the similarity of architectures of development of different parameters (energy efficiency, information efficiency and productivity), we can write the total (integral, generalized) expression, which helps us to evaluate the effectiveness of new physical processes and production technologies, which are based on these new physical phenomena and processes of transformation of matter, energy and information [4]:

$$U_{integral} = \frac{t^b_f + t^b_h}{t^n_f + t^n_h} * \frac{E^n_{fp} + E^n_{fv}}{E^b_{fp} + E^b_{fv}} * \frac{I^n_{in} + I^n_{ot} + I^n_{us}}{I^b_{in} + I^b_{ot} + I^b_{us}} = U_t U_e U_i \quad (6)$$

t^b_f - time (or cost) required to perform a physical process [s];
t^b_h, t^b_h, - the time associated with the costs of the operation and other processes (including manual labor), which allow the execution of the basic physical process b and new physical process n [s];
I_{in} - the magnitude of input data, I_{ot} - the magnitude of output information, I_{us} - the magnitude of trasformed data, which are used by the system.

As an example, we will consider the manufacturing process of part production. There are two process types, which have absolutely different architectures:

- *Basic manufacturing process.* This process is based on the model of mass decrease, which is performed with the help of plastic deformation operation, which forms dimension parameters and part shape parameters. Other part properties are defined by processes of property change (see Fig.1);
- *New manufacturing process*. This process is based on the model of mass increase, which is performed with the help of melting process, which forms dimension parameters and part shape paramaters (this process is usually called as additive

process). Other part properties are defined by processes of property change (see Fig.1);

$$U_t = \frac{t_f^b + t_h^b}{t_f^n + t_h^n} = \frac{\frac{V^b}{Q^b} + t_h^b}{\frac{V^n}{Q^n} + t_h^n} = \frac{Q^n}{Q^b} * \frac{V^b + Q^b t_h^b}{V^n + Q^n t_h^n} =$$

$$= \frac{Q^n}{Q^b} * \frac{V_{intern}^w + V_{extern}^w + V_{extern}^{w+} + Q^b t_h^b}{V - (V_{intern}^w + V_{extern}^w + V_{extern}^{w+}) + Q^n t_h^n} =$$

$$= \frac{Q^n}{Q^b} * \frac{(V_{intern}^w + V_{extern}^w + V_{extern}^{w+}) + (t_h^b/(t_f^b)}{V - \left(V_{intern}^w + V_{extern}^w + V_{extern}^{w+} + \frac{(t_h^n}{(t_f^n}\right)} =$$

$$= \frac{Q^n}{Q^b} * \frac{(V_{intern}^w + V_{extern}^w + V_{extern}^{w+}) + (t_h^b/(t_f^b)}{V_n^w + \left(\frac{(t_h^n}{(t_f^n}\right)} = \frac{Q^n}{Q^b} * \frac{\sum V_{sum}^v + (t_h^b/(t_f^b)}{V_n^v + (t_h^n/(t_f^n)} \quad (7)$$

Q^b, Q^n - the speed of material removal, which is performed with the help of basic manufacturing process or by adding of material with the help of new physical process [m^3/s];

V^b, V^n - the volume of removed and added material respectively, [m^3]

V_n^w - the real volume of the part, which is produced with the help of basic or new physical processes, [m^3];

t_h^b, , t_h^n- time associated with the costs of other operations and processes (including manual labor), which ensure the implementation of basic and new manufacturing processes [s];

ξ - relative coefficient (ratio of initial workpiece volume to the volume of removed material).

$$V^n = V_w^n = V - (V_{intern}^w + V_{extern}^w + V_{extern}^{w+}) = V - \sum V_{sum}^w \quad (8)$$

If time, which is associated with the costs of other operations and processes (including manual labor) and ensures the implementation of basic and new machining processes, is small or can be neglected during the evaluation, we can get the following equation (9) :

$$U_t = \frac{Q^n}{Q^b}\frac{V^b}{V^n} = \frac{Q^n}{Q^b} * \frac{(V_{intern}^w + V_{extern}^w + V_{extern}^{w+})}{V - (V_{intern}^w + V_{extern}^w + V_{extern}^{w+})} = \frac{Q^n}{Q^b}\frac{1}{\xi - 1} = \frac{Q^n}{Q^b}\frac{1}{\xi^w}$$

$$\xi = \frac{V}{(V_{intern}^w + V_{extern}^w + V_{extern}^{w+})} = \frac{V}{\sum V_{sum}^w} \quad (9)$$

$$\xi^w = \frac{V - (V_{intern}^w + V_{extern}^w + V_{extern}^{w+})}{(V_{intern}^w + V_{extern}^w + V_{extern}^{w+})} = \xi - 1$$

Q^b, Q^n - specific productivity, [m³/s];

V_{intern}^w - internal volumes of the workpiece, which are removed with the help of basic physical process (cutting operation);

V_{extern}^w - external volumes of the workpiece, which are removed with the help of basic physical process (cutting operation);

V_{extern}^{w+} - additional external volumes of the workpiece, which are removed with the help of basic physical process (cutting operation);

$\sum V_{sum}^w$- the sum of all volumes of the workpiece, which are removed with the help of basic physical process (cutting operation).

$$U_e = \frac{\left(\frac{\varepsilon_{fp}^n}{\varepsilon_{fp}^b}\right)(\xi - 1) + \frac{E_{fv}^n(\xi - 1)}{\varepsilon_{fp}^b * V_{\text{Д}}^n}}{1 + \frac{E_{fv}^b(\xi - 1)}{\varepsilon_{fp}^b * V_w^n}} =$$

$$= \frac{(\xi-1)[\left(\frac{\varepsilon_{fp}^n}{\varepsilon_{fp}^b}\right)\left(\varepsilon_{fp}^b * V_w^n\right) + E_{fv}^n]}{[\left(\varepsilon_{fp}^b * V_{\text{Д}}^n\right) + E_{fv}^b(\xi-1)]} = \frac{(\xi-1)[\left(\varepsilon_{fp}^n * V_w^n\right) + E_{fv}^n]}{[\left(\varepsilon_{fp}^b * V_w^n\right) + E_{fv}^b(\xi-1)} \quad (10)$$

here: ε^b , ε^n - specific energy intensity of basic and new physical processes , [J/m^3].

So the generalized equation, which can be used for evaluation of integral parameter of effectiveness of implementation of new physical machining process, looks like that:

$$U_{integral} = U_t U_e U_i =$$

$$\frac{Q^n}{Q^b}\frac{V^b + Q^b t_h^b}{V^n + Q^n t_h^n} * \frac{(\xi - 1)\left[\left(\varepsilon_{fp}^n * V_w^n\right) + E_{fv}^n\right]}{[\left(\varepsilon_{fp}^b * V_w^n\right) + E_{fv}^b(\xi - 1)} * U_i =$$

$$= \frac{Q^n}{Q^b} * \frac{\sum V_{sum}^w + Q^b t_h^b}{V_w^n + Q^n t_h^n} * \frac{(\xi-1)\left[\left(\varepsilon_{fp}^n * V_w^n\right) + E_{fv}^n\right]}{[\left(\varepsilon_{fp}^b * V_w^n\right) + E_{fv}^b(\xi-1)} * U_i \quad (11)$$

If we assume that overall volume of workpiece data is equal for all cases, we can get the following expression:

$$U_i = \frac{I_{in}^n}{I_{in}^b} = \frac{-(3\frac{1}{\varepsilon_c^n})^3 log_2(\varepsilon_c^n)}{-(3\frac{1}{\varepsilon_c^b})^3 log_2(\varepsilon_c^b)} = \frac{[\frac{V - (V_{intern}^w + V_{extern}^w + V_{extern}^{w+})}{(\delta_v^n)^3}] log_2(\varepsilon_c^n)}{[\frac{(V_{intern}^w + V_{extern}^w + V_{extern}^{w+})}{(\delta_v^b)^3}] log_2(\varepsilon_c^b)}$$

$$= [\frac{\delta_v^b}{\delta_v^n}]^3 * \left[\frac{V - (V_{intern}^w + V_{extern}^w + V_{extern}^{w+})}{(V_{intern}^w + V_{extern}^w + V_{extern}^{w+})}\right]$$

$$* \frac{log_2\left[\frac{(\delta_v^n)^3}{V - (V_{intern}^w + V_{extern}^w + V_{extern}^{w+})}\right]}{log_2\left[\frac{(\delta_v^b)^3}{(V_{intern}^w + V_{extern}^w + V_{extern}^{w+})}\right]}$$

$$= (\xi - 1) * [\frac{\delta_v^b}{\delta_v^n}]^3 * \frac{log_2\left[\frac{(\delta_v^n)^3}{V - (V_{intern}^w + V_{extern}^w + V_{extern}^{w+})}\right]}{log_2\left[\frac{(\delta_v^b)^3}{(V_{intern}^w + V_{extern}^w + V_{extern}^{w+})}\right]}$$

$$= (\xi - 1)$$

$$* [\frac{\delta_v^b}{\delta_v^n}]^3 \frac{log_2(\delta_v^n)^3 - log_2[(\xi - 1)(V_{intern}^w + V_{extern}^w + V_{extern}^{w+})]}{log_2(\delta_v^b)^3 - log_2[(V_{intern}^w + V_{extern}^w + V_{extern}^{w+})]} \quad (12)$$

here, δ_v^b, δ_v^n - maximum accuracy of characteristic dimension, which is achieved with the help of basic or new physical machining process.

Then, if we substitute the components, we can get the following equation:

$$U_{integral} = (\xi - 1)^2 * \frac{Q^n}{Q^b} * \frac{\sum V_{sum}^w + Q^b t_h^b}{V_w^n + Q^n t_h^n} * \frac{\left[\left(\varepsilon_{fp}^n * v_w^n\right) + E_{fv}^n\right]}{\left[\left(\varepsilon_{fp}^b * v_w^n\right) + E_{fv}^b(\xi-1)\right]} *$$

$$[\frac{\delta_v^b}{\delta_v^n}]^3 * \frac{3log_2(\delta_v^n) - log_2[(\xi-1)(V_{intern}^w + V_{extern}^w + V_{extern}^{w+})]}{3log_2(\delta_v^b) - log_2[(V_{intern}^w + V_{extern}^w + V_{extern}^{w+})]} \quad (13)$$

If time, which is associated with the costs of other operations and processes (including manual labor) and ensures the implementation of basic and new machining processes t_h^b *or* t_h^n , is small or can be neglected during the evaluation, we can get the following expression:

$$U_{integral}$$

$$= (\xi - 1)^2 * \frac{Q^n}{Q^b} * \frac{\left[\left(\varepsilon_{fp}^n * v_w^n\right) + E_{fv}^n\right]}{\left[\left(\varepsilon_{fp}^b * v_w^n\right) + E_{fv}^b(\xi - 1)\right]} * [\frac{\delta_v^b}{\delta_v^n}]^3$$

$$* \frac{3log_2(\delta_v^n) - log_2[(\xi - 1)(V_{intern}^w + V_{extern}^w + V_{extern}^{w+})]}{3log_2(\delta_v^b) - log_2[(V_{intern}^w + V_{extern}^w + V_{extern}^{w+})]} \quad (14)$$

If $U_{integral}$ =1, all physical processes are equally effective; if $U_{integral} >$ 1, new physical process is more effective (the greater this parameter, the more efficient the process). Analysis of this expression allows us to solve direct assessment problems and inverse problems.

For example, analysis of U_t (comparison of additive process and standard process of material removal) helps us to reach a clear conclusion about the feasibility of the production of topologically complex products (complex spatial form (both internal and external forms)) with the help of additive methods. The more complex is the product, the greater is the effect of productivity. If ξ =1,1, Q^n=1 (standard unit) and Q^b=5 (standard unit), we can get U_t= 2 - double growth of productivity efficiency. If we have equal additional operations and procedures $t_h^b = t_h^n$ =1(standard unit)), we can get

$$U_t = \frac{1}{5} * \frac{\sum V_{sum}^w + 5*1}{V_w^n + 1*1} \quad (15)$$

3. Case study

Let`s determine the effectiveness of the additive process of part production with respect to the machining process. Let`s take as an example the production of a hollow cylinder. Hollow cylinder hast he following dimensions: R_{w_extern} – the external radius of the workpiece; R_{p_extern} – the external radius of the part; R_{p_intern} - the internal radius of the part; L – the length of the cylinder. Then the volume of removed material is equal to:

$$\sum V_{sum}^w = (V_{intern}^w + V_{extern}^w + V_{extern}^{w+}) = \pi L(R_{p_{intern}}^2 + R_{w_{extern}}^2 - R_{p_{extern}}^2)$$

the volume of the machined part is equal to:

$$V_w^n = \pi L(R_{p_{extern}}^2 + R_{p_{intern}}^2 = \pi L R_{w_{extern}}^2 - \pi L(R_{p_{intern}}^2 + R_{w_{extern}}^2 - R_{p_{extern}}^2)$$

$$\xi = \frac{\pi L R_{w_{extern}}^2}{\pi L(R_{p_{intern}}^2 + R_{w_{extern}}^2 - R_{p_{extern}}^2} = \frac{R_{w_{extern}}^2}{(R_{p_{intern}}^2 + R_{w_{extern}}^2 - R_{p_{extern}}^2)}$$

Let`s define the integral parameter, taking into account the following initial data: L = 0,1 m; R_{w_extern}=0,06m; R_{p_extern} =0,05m; R_{p_intern} =0,02m; V_w^n =2,1*10$^{-4}\pi$ [m^3]; $\sum V_{sum}^w$ =1,5*10^{-4} π [m^3]; ξ = 2,4; Q^n = 4*10^{-8} [m^3/s] [2,4]; ε_{fp}^n = 230*10^3 [J/m^3]; E_{fv}^n =9,7*10^6 π [J]; δ_v^n = 2·10^{-5} [m] [5,6]; t_h^n =0, Q^b = 4*10^{-7} [m^3/s] [5,6]; ε_{fp}^b = 10^4 [J/m^3] [4,5,6]; E_{fv}^b =4,2*10^5 π [J]; δ_v^b = 2·10^{-6} [m]; t_h^b =0.

$$U_{integral}^I = U_t * U_e * U_i = (0{,}072) * (30{,}4) * (1{,}12 * 10^{-3}) = 2{,}45 * 10^{-3}$$

Let`s analyse the second option of production of more complex part, taking into account the following initial conditions:

δ_v^n = 2·10^{-6} [m]; V =3,6*10$^{-4}\pi$[m^3], V_w^n =0,475*10$^{-4}\pi$[m^3], $\sum V_{sum}^w$ =0,312*10$^{-4}\pi$[m^3]; ξ = 1,15; t_h^b =450 [s].

$$U_{integral}^{II} = U_t * U_e * U_i = (0{,}7785) * (3{,}1) * (1{,}07 * 10^{-1}) = 2{,}58 * 10^{-1}$$

4. Results & discussion

Thus, despite the fact that the additive physical process is worse than the physical process of plastic deformation (machining process) both in performance and in the energy performance, in many cases its application is more efficient, and in some applications, it may be even difficult to replace it. In this case, it is obvious that additive method of material removal is much more effective, than abovementioned two compared methods. That is why the proposed system of parameter evaluation helps us to conduct the analysis of different implementation options and search of new directions and solutions.

5. Conclusion

The Comparative Integral Manufacturing Efficiency is the product of Quality rate, Effectiveness, Availability, devided by the product of (used Energy, used material, Emission ratio). Abovementioned systematic architectures and outline help us to define possible future directions of research of manufacturing processes and necessary associated technologies, assess ways of increasing technological competitiveness of production, select the strategy for the development and optimization of processes and technology applications. In this case material properties are taken into account during the analysis of physical processes. The estimations, obtained with the help of a systematic single model, are indicated. These estimations are required for determining whether the new machining process can be implemented. These estimations are based on integral and some individual criteria.

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