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ANALYSIS OF THE RATIONAL ROUTE OF ALUMINIUM ALLOY CASTINGS MECHANICAL TREATMENT ON BASIS OF RELIABILITY CRITERION

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Abstract: Modern technologies of mechanical treatment of machine parts as well as their assembly ensure a high level of technical requirements to the machine parts at minimum possible technological manufacturing cost. However, the competitiveness of products is determined, in addition to qualitative and economic indicators, by reliability characteristics: reliability, durability, repairability, saving which manifest themselves in products operation. The reliability parameters are formed in the products design. They are ensured during the machine parts manufacturing and are realized under machine parts exploitation. Therefore the problem of reliability is a comprehensive one. In the practice of machine-building industry the cutting modes are selected based on the cost-effectiveness of the technical requirements ensuring. The proposed methodology of the rational selection of cutting modes based on the reliability criterion with application of the LM-hardness method is developed. According to this method a degree of dispersion of the material mechanical characteristics, in particular, hardness, is accepted as the damageability parameter. In experimental researches the influence of the cutting modes parameters on the change of the Weibull homogeneity coefficient m and technological damageability W of the aluminium alloy castings received in sand moulds is analyzed. The recommendations on the technological process design with rational treatment modes with the purpose of reduction of the damage of aluminium alloy machines parts are developed.
Keywords: reliability, infallibility, durability, technological damageability

1. RELEVANCE OF THE PROBLEM

Modern technologies of mechanical treatment of machine parts as well as their assembly ensure a high level of technical requirements to the machine parts at minimum possible technological manufacturing cost. However, the competitiveness of products is determined, in addition to qualitative and economic indicators, by reliability characteristics: infallibility, durability, repairability, preservation which manifest themselves in products operation [1-4].

The Life Cycle of a machine is the main object of research investigation. The reliability parameters are connected with all stages and substages of Life Cycle of a machine (Figure 1).

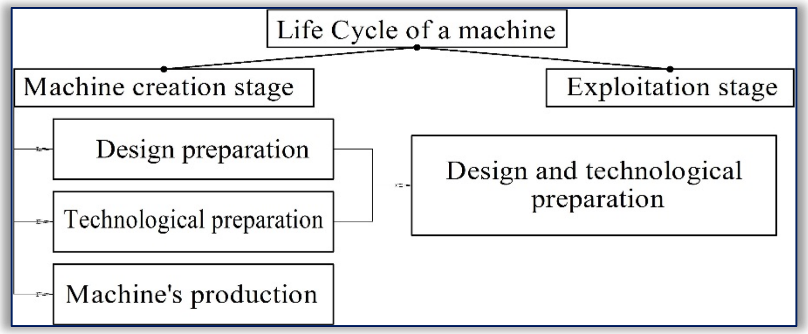


Figure 1. Stages and substages of Life Cycle of a machine

The reliability parameters are formed in the products design. They are ensured during the machine parts manufacturing and are realized under machine parts exploitation. Therefore the problem of reliability is a comprehensive one [4,5].

The infallibility (reliability) is the ability of product to perform its functions continuously during exploitation. We launch a machine and do not interfere in it work. The durability is the ability of product to perform its functions during exploitation with a compulsory holding maintenance and equipment repair. Consequently, the reliability of the product is determined by its infallibility and durability. The first parameter considers the total continuous operation of the product without any interference to maintain working capacity. The durability of the product, on the contrary, characterizes the part's work during it exploitation and takes into account that the long service of the machine is impossible without repair and preventive measures that restore the capacity for work, lost during using [5-7].

The repairability is the product's ability to realization maintenance and equipment repair. The saving is the product's ability uphold infallibility, durability and repairability during storage and transportation. The main characteristics of infallibility, durability, repairability, maintainability are described in Table 1.

Table 1. The main characteristics of infallibility, durability, repairability, maintainability

№	The title of parameter	Symbol	Describing
The main characteristics of infallibility			
1.	Probability of non-failure (reliability coefficient)	P(t)	The probability that in a given time interval t=T (or within a given life cycle) does not occur failure.
2.	The average time to failure	T_{av}	It shows how many hours (at the average) product will run until the first failure.
3.	The average time on the failure	T_0	It refers to the reliability rating of recoverable products.
4.	The bounce flow parameter	w(t)	Attitude of expectation of the failures number of recoverable object for it small operating time before the value of this operating time.
5.	The failures intensity	$\lambda(t)$	Conditional density of occurrence of the object failure on condition that by considering instant of time failure did not arise.
6.	The probability of certain type failure	q_0	Probability of the fact that within given operating time of part failure of given type will arise.
The main characteristics of durability			
7.	The average resource	T_{av}	The average operating time to limit state
8.	The reviously nominated resource	$T_{r.n.r.}$	The nominated resource installed at transfer of the part to official tests.
9.	The initial nominated resource	$T_{i.n.r.}$	The nominated resource installed in the beginning of receipt of the first serial part to exploitation.
10.	The resource to first repair	$T_{r.1}$	Operating time of part from the beginning of exploitation to first repair
11.	The interrepair time	Tr.o.c.	The operating time between adjacent repairs
12.	The gamma-percentage resource	γ	Total operating time, during which object did not reach a limiting condition with probability γ, expressed in percentage.
The main characteristics of repairability			
13.	The average time of restoration of the operable condition	$T_{rest.}$	The expectation of restoration time of the object's operable condition after its refusal
14.	The probability of restoration of the operable condition	P_B	Probability of the fact that the time of restoration of operable condition of the object will not exceed permitted value
The main parameters of preservation			
15.	Probability of restoration of the operable condition	P_B	The expectation of maintainability period

The infallibility and durability are the main indicators of reliability.

The infallibility is characterized by technical state of the object: serviceableness, malfunction, operability, nonoperability, defect, damage and failure. Each of these positions is characterised by the set of the values of parameters describing condition of the object, and qualitative signs. The nomenclature of these parameters and signs, as well as the limits of their admissible changes are installed by standard documentation on object. Transition of objects from one condition to other takes place usually owing to damage or failure. Common outline of conditions and events is presented in Figure 2. Operable object in contrast to serviceable should satisfy just those requirements of standard and technical and design documentation, performance of which are ensured its normal application to destination. Transition of the element from serviceable to failure condition takes place owing to defects. Term "defect" is applied, mainly, on production and repair substages. In these cases it is required to take into account separately each particular discrepancy of the object to requirements installed by standard documentation. Term "malfunction" is applied during exploitation of objects, when it is required to take into account changes of condition of elements without reference to the quantities of discovered defects. Object has one or more determined defects, while on malfunction condition (Figure 3) [7].

The durability is characterized by the limiting condition of the object. The limiting condition of the object is characterized by such condition, at which its further application to destination is inadmissible or inexpediently, or restoration of serviceable or operable conditions is impossible or inexpediently. Sign or the set of signs of limiting condition of the object installed in standard and technical and design documentation, serves by the criterion of limiting condition [5-7].

The prediction of condition of parts during their exploitation, foreseeability of opportunity of their break-downs and failures is a difficult problem which requires decision at substage of technological preproduction of production.

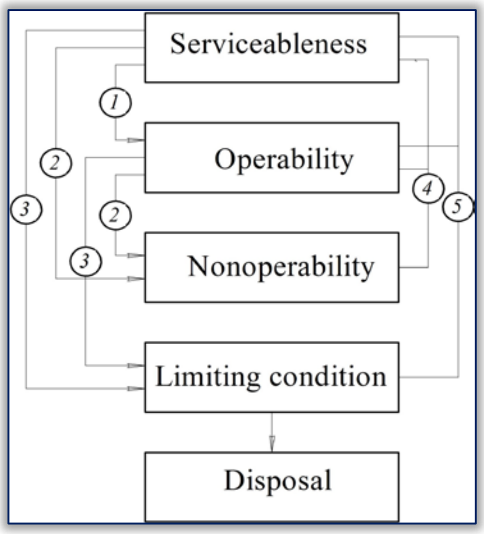


Figure 2. The scheme of constant conditions and objects events: 1 – damage, 2 – failure, 3 – transition of the object into limiting condition, 4 – restoration, 5 – repair

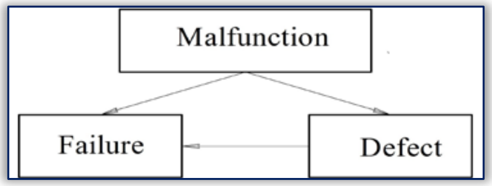


Figure 3. Conditions and events of the object

2. LITERATURE SURVEY

The reliability is one of the most important properties, which determine functional indicators of any technical devices and system. Safety, economical efficiency, operational life (resource conservation), competitiveness depend on reliability [6].

The systemic approach of reliability development is a leading conception, on the basis of which it is solved the problem of improving of technician reliability at the present stage of mechanical engineering development. Reliability supply systems, making the most important part of quality supply system, cover all life cycle of the part from designing to exploitation. At the same time the methods of achieving of reliability proper level are specific for each stage of life cycle [5,6].

So, the main methods of achievement of design reliability are choice of the appropriate materials, safety factors, application of rational designs, various reserving outlines etc. The technological reliability is ensured by means of defectless stable technological processes of production. The exploitation reliability is defined by the organization of maintenance, where at present a few tendencies are traced [6].

Classical tendency based on statistical theory of reliability in the conditions of large-scale production, allows to plan service strategies on the average for the consignment of identical parts and optimum service of each separate part of this consignment doesn't guarantee. The modern tendency are assurance of reliable technician functioning. It develops methods of service of each particular part for its actual conditions [6,7].

But in addition, technological processes of manufacturing, assembling and the control of the parts should provide with least expenditures of the time and facilities to ensure required level of quality, including reliability. However communication of parameters of technological process with reliability of finished product is quite difficult. Besides, the reliability requirements, as a rule, are in conflict with such main requirements of the technological process, as its productivity and economical efficiency [5]

The engineer usually cannot argue particular events connected with increase of reliability of the parts, as his results will have an effect just during a long period of their exploitations [5].

At the same time all organisation of production of particular part, using technjlogical processes and control methods have decisive influence on reliability indicators (Figure 4) [4,5].

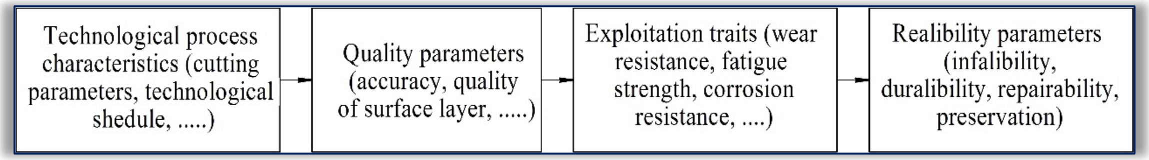


Figure 4. The dependence scheme of the reliability parameters about the technological process level

All components of technological process (processing techniques and used equipment, sequence of operations, cutting parameters, control methods) define its initial parameters and primarily the indicators of quality of the part specified by the designer in technical requirements (accuracy, quality of the surface, physical specifications etc.) [5].

Perfection of technological process to a large extent defines and reached level of reliability of the part, as exactly reliability laid by the designer, is ensured during manufacturing of the part. Technological methods of reliability ensuring have same crucial importance as constructive and exploitative. However the role of the technology in the problem of reliability still entirely not determined till now [1-3,5].

Various kinds of energy, acting in machine, cause in its knots and details a different processes lowering initial parameters of part. These processes are connected, as a rule, with difficult physical and chemical phenomena and result in deformation, wear-and-tear, break-down, corrosion and the other kinds of damages. It, in turn, involves change of output parameters of the part that can result in failure (Figure 5) [5].

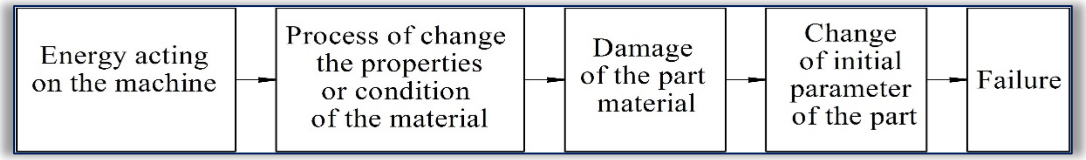


Figure 5. The connections in machine during it exploitation

It is to be noted that in literature about reliability of machines they frequently use term “defect”, i.e. such condition of the part, at which it does not correspond at least one of technical requirements, however it remains in operable condition. At the same time defect is considered as possible reason of failure. It is noted [5] that term “defect” should be attributed only for result of technological process, and the term “damage” should be attributed for result of influence on machine during it exploitation.

ISO 8785:1998 [8] describe the term “imperfection”. The surface imperfections are determined in accordance with the surface functional assignment and their characteristics - length, depth, width, height, relative density of the arrangement etc. These parameters are defined by simple measurements on the following definitions basis (ISO 8785:1998) [4,8]:

- surface imperfection length SIM_l – greatest dimension of the surface imperfection, measured parallel to the reference surface;
- surface imperfection width SIM_W – greatest dimension of the surface imperfection, measured normal to the surface imperfection length and parallel to the reference surface;
- single surface imperfection depth SIM_{sd} – greatest depth of the surface imperfection, measured from and perpendicular to the reference surface;
- combined surface imperfection depth SIM_{cd} – greatest depth of the surface imperfection, measured from and perpendicular to the reference surface;
- single surface imperfection height SIM_{sh} – greatest height of the surface imperfection, measured from and perpendicular to the reference surface;
- combined surface imperfection height SIM_{ch} – distance between the reference surface and the upper most point of the surface imperfection, measured from and perpendicular to the reference surface;
- surface imperfection area SIM_a – area of a single surface imperfection projected onto the reference surface;
- total surface imperfection area SIM_t – area equal to the sum of the individual surface imperfection areas, within the agreed limits of discrimination;
- surface imperfection number SIM_n – number of surface imperfection on the total real surface, within the agreed limits of discrimination;

— number of surface imperfections per unit area SIMn/A – number of surface imperfections on the specified surface imperfection evalution area A.

Therefore influence of defects on parameters of quality during manufacturing of the details and assembling of machines at the substage of technological preproduction of production requires further theoretical and practical researches.

3. METHODS OF RESEARCH

The technological damageability W in many researches of reasons of material fracture during exploitation time is not related with structure. Only with the using of energy attitudes for the description of the processes of accumulating of damage [9, 10] it is considered that as a total result of viscoplastic deformation, two kinds of microdamages develop - along the body and along the grain boundaries.

The control methods of the level of material damageability during the operating time by the results of direct and secondary measurements of the metal mechanical properties without fracture are known [9,10].

Therefore necessity in development of the evaluation method of structure degradation of material as a damages accumulation result during the operating time had emerged [4].

The LM-hardness method developed under the academician A. A. Lebedev have used for analysis and evaluation of transformation of inhomogeneity of subsurface layers of samples received by casting, into technological damages during machining. According to this method the level of dispersion of material mechanical characteristics after machining time at various stress levels is accepted as a parameter of damageability. LM -hardness method is easier to implement, using a hardness as mechanical characteristic. The value of hardness is used for parameters indirect evaluation by the structure and other properties [4,9,10].

The parameter that integrally characterizes the state of the material when processing the results of hardness measurements is homogeneity. The homogeneity is estimated by the Weibull coefficient (*m*). A large value of the coefficient (*m*) comply with a low level hardness dispersion and a low damageability degree; for the lower value, conversely, the damageability degree is higher [9,10].

The Weibull distribution is calculated by [4]:

$$P(\sigma)=1-e^{-\left(\frac{\sigma}{k}\right)^{m}} \tag{1}$$

The Weibull 's homogeneity coefficient (*m*) is calculated by [9,10]:

$$m=\frac{d(n)}{2{,}30259\cdot S(\ell g(H))}\,, \tag{2}$$

where $d(n)$ is a characteristic that depends on the number of measurements n;

$$S(\ell g(H))=\sqrt{\frac{1}{n-1}\cdot\sum_{i=1}^{n}\left(\ell g(H_i)-\overline{\ell g(H)}\right)^2} \tag{3}$$

$$\overline{\ell g(H)}=\frac{1}{n}\cdot\sum_{i=1}^{n}\ell g(H_i) \tag{4}$$

The technological damageability W is calculated by:

$$W=\frac{m_{\max}-m_i}{m_{\max}}, \tag{5}$$

where m_i is the value of the Weibull coefficient on the i-th measurement line (plane); m_{max} is the maximum value of the Weibull coefficient for a series of measurements.

However, if unknown microhardness values distribution on sample height, the value of damageability W is inexpedient to operate. In this case the evaluation of the structural condition of material have implemented by means of the Weibull coefficient (*m*) [4].

The reliability coefficient *P(t)* of the technological process will be described by formula….. [1], [4]:

$$P(t)=\prod_{i=1}^{m}\left[1-(1-P_0)\cdot\left(1-P_{x_i}\right)\cdot(1-P_k)\right], \tag{6}$$

where $P_0(t)$, $P_{x_i}(t)$ is the reliability coefficient during blanking and intermediate operations, P_k is the reliability coefficient in control operations.

From the position of the theory of probability [12]:

$$P(t)+W(t)=1\,, \tag{7}$$

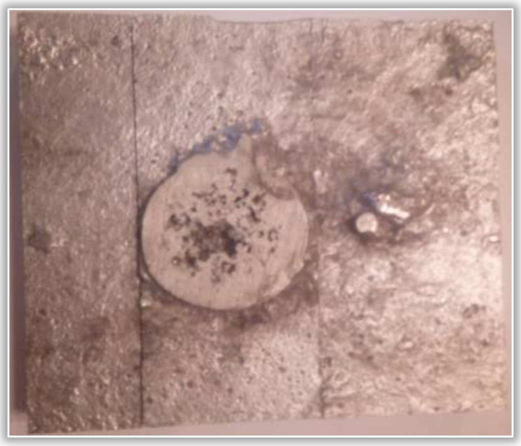
where $W(t)$ is failure of the machine part during it machining and exploitation.
With account of (7) Eq.(6) is written as:

$$W(t)=\prod_{i=1}^{m}\left[1-W_0\cdot W_{x_i}\cdot W_k\right], \quad (8)$$

where $W_0(t)$, $W_{Xi}(t)$ is the probability of failure during blanking and intermediate operations, W_k is the probability of failure in control operations.
The probability of failure $W(t)$ is identified with the value of the technological damageability W from the position of the technology of engineering. With account of (7) the technological damageability W is in inverse proportion with reliability coefficient $P(t)$.
Therefore we offer to use the technological damageability W for the evaluation of the infallibility of machines parts.

4. PLANNING AND ANALYSIS OF EXPERIMENTAL RESEARCHES

Experimental researches led for analysis of the rational route of aluminium alloy castings mechanical treatment on the basis of the technological damageability, as infallibility parameter of the part.
The blank (sizes 165x155x22 mm, material АК21М2,5Н2,5 GOST 1853-93) was cast in sand mold (Figure 6). After crystallization the blank was divided in three samples: with small and big risers and with gate [4].
The surfaces of samples were processed on universal-milling machine tool 676 (t = 0,2-2 mm; S_{min} = 42 mm / min; n = 640 min-1) by end milling cutter Ø 45 mm (z = 2). Two machining series were carried out. The control of the parameters of surface layer was implemented after each machining [4].
The hardness were measured in five cross-sections on distances 2, 4, 7, 12, 17 mm from the surface of the casting (on 30 values) after machining.
The measurement are implemented for samples 1, 2 (Figure 6) on the device TP-5006 GOST 23677-79 on scale of N by means of ball Ø 3,175 with load 588,4 H [4].



1 2 3
Figure 6. The samples for experimental researches: 1 - with small riser; 2 - with gate; 3 - with big riser

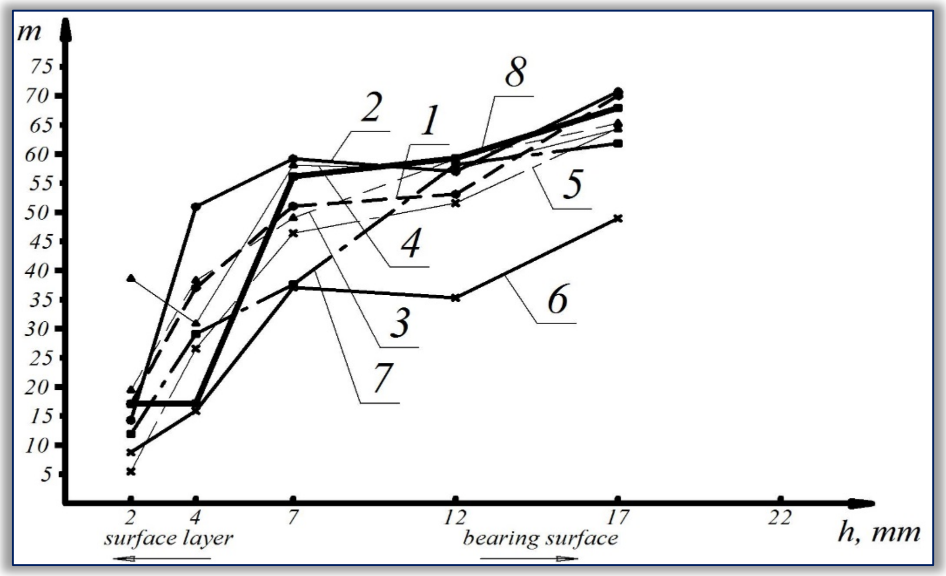


Figure 7. The Weibull coefficient (m) according thickness of samples 1 and 2 (Figure 6): 1, 2 - from small riser fellow for the first and second experience series respectively; 3, 4 - from opposite end surface from small riser a fellow for first and second experience series respectively; 5, 6 - for gate from small riser a fellow for the first and second experience series respectively; 7, 8 - for gate from big riser for the first and second experience series

The Weibull coefficient (m) was computed by equations (2-4). The change of Weibull coefficient (m) according thickness of the sample is presented in Figure 7.

The damageability W of casting material was calculated by equation (5) in medium of the Mathcad 15 by researches results. The change of damageability W according thickness of the sample is presented in Figure 8.

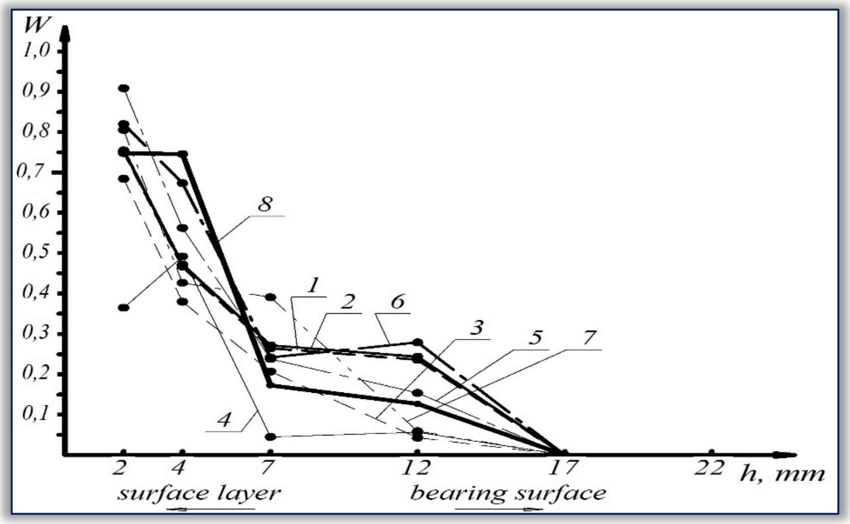


Figure 8. The material damageability dependence's schedule W according thickness of samples 1 and 2 (Figure 6): 1, 2 - from small riser fellow for the first and second experience series respectively; 3, 4 - from opposite end surface from small riser a fellow for first and second experience series respectively; 5, 6 - for gate from small riser a fellow for the first and second experience series respectively; 7, 8 - for gate from big riser for the first and second experience series

The experimental research results show.

- The maximum quantity of technological damages is typical of the zones of the surface layer at a depth up to 2 mm. The Weibull homogeneity coefficient (m) has the minimum value and the technological damageability W has the largest value for the sample with a gate: more - for the side of the small risert, less - for the side of the big riser. It is explained by the specific features of the material hardening process, impurityies presence, heterogeneities in surface layer and cavity biased from symmetry axis to the directionof the small riser.
- The stabilisation of the damageability takes place for sample with small riser for the first and second experience series at moving deep into material from 2 to 4 mm. At the same time in the cross-section from gate the damageability is more. It evidences about influence of the form design elements of to impurityies and heterogeneities on distribution of casting section. Damageability grows for sample with gate at moving to shrinkage cavity (the second experience series).
- At the depth of 4 to 17 mm the technological damageability values stabilize. This is proved by the increase in the Weibull homogeneity coefficient values (m) (decreasing values of the technological damageability W) and their approach to the cross-section with the quickest solidification of the melt.

5. CONCLUSIONS

The main conclusions have been drawn basing on the researches results.

- The technological damages on the surface layers of the machine parts during blanking operations and after machining should be analyzed by the level of hardness dispersion.
- For the first time the technological damageability W is proposed as a criterion for the machine parts reliability evaluation at the substage of machine design.
- Further research should be carried out for a more wide nomenclature of machine parts and materials to introduce the proposed technique into the practice of modern mechanical engineering production.

Note:

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