THE METHOD OF TECHNICAL CONDITION DESCRIPTION DEDICATED FOR ENGINEERING SOFTWARE DEVELOPMENT

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Abstract: The conscious technical condition description preparation of technical means elements should be supported with computer aid software and a database. The basic and the most important aspect is elimination of classes interchange in a description, which is present and common in industry. The article presents wide comparison of wear classifications that can be met in literature, and which are the basis for technical mean description. Furthermore the proposed classification should have assigned direct coding for each class in order to maintain correct relations. The proposed description method consist division to main classes groups as: wear, damage and destruction. Paper presents examples of classification assignment for elements technical state description stored in data base table with mentioned coding. It's also possible to gather description in tables with various data (measurements values of quantities, photographs, thermographs etc.).
Key words: technical condition, computer aid overhaul, repair, wear, damage, service

1. INTRODUCTION

The nomenclature is set, in order to distinguish elements and parts of elements, for instance gear-shaft is an element while keyway is a part of that element. The technical condition descriptions preparation of technical means elements have to be supported with a strictly defined terms in order to prepare repair and overhaul process with a needed precision. In comparison to a repair process an overhaul process is planned, and it range of disassembly is commonly greater or affects, whole technical mean. An overhaul process is also repeatable in aspect of it periodical character (it is planned). The proposed Wear, Damage and Destruction Description Method (WDDDM) is based on the Enforcement of Micro and Macro Environment (EMME) classification (Table 1), in order to assign wear classes to specific enforcements. The wear classification has to be supported with definition. Thus the wear term is defined as: transformation of an element form (material, design, assembly relations between elements), which has a negative influence to it technical state (after an initial grind-in process); predictable according to operation time periods (cycles), place and range of occurrence. Wear occur during conditions that are predicted by designers (for example: pitting mechanical fatigue of a gear tooth, mechanical abrasion of a piston sealing rings, mechanical cavitation of a turbine blade, fretting fatigue of shaft step – bearing contact surface). While damage unlike wear is unpredictable according to time, place and range of occurrence. Damage is a transformation of element form (material, design, assembly – relations between elements), which has negative influence to it technical condition and appears, as result of unpredicted (by designers) service, random events or transgression of an acceptable wear – exceeding of a dimensional tolerance range (for ex.: pits group as a result of corrosion progression, cut of a roof support shield fraction as a result of mining drill head). Destruction has binary description as 0 or 1 state. When element is worn out and damaged in a range that is impossible or not worth to perform a refurbishing process, then a destruction state is described with the 1 digit. When a state of destruction is set as 0 digit then element could be assembled again or refurbished in a reference to it technical state. Proposed solution is already implemented in the previously described (in other article [8-10]) Computer Aided Overhaul - CAO software. In order to present that the WDDDM is universal, unambiguous and possible to apply in industry, two very different examples are presented. The first one is cam shaft and second one is transmission box housing.

2. COMMON WEAR CLASSIFICATIONS

One selected wear classification should be applied for condition description. For example in situation where a part of an element has to be refurbished, proper description is needed in order to assign correct technological means and technological process of worn and damaged element.

Table 1. Set of common classifications of wear processes [15, 6, 1, 14]

No.	Kislik	Barwell and Stroug	Kostecki	Lisowski	EMME
1	Mechanical destruction of fastened irregularities	In consequence of adhesion	Type I tacking (as a consequence of adhesion)	Micro-slicing process- abrasive	Mechanical processes, wear: abrasive, adhesive, fatigue, pitting, cavity, erosion
2	Fatigue destruction under the influence of fastened irregularities	In consequence of corrosion	Through oxidation	Local welding process –adhesive	Chemical processes: chemical corrosion, electro-chemical corrosion, abrasive - wear
3	Destruction under the influence of crush and embrittlement enhancement	Caused by existence and activity of abrasive particles	Type II tacking (thermal)	Local de-cohesion process of material particles as a consequence of multiple alternative stresses	Thermal processes: thermal fatigue, oxidization
4	Peeling of oxidized metal membranes	Caused by pushing of a soften body with harden body irregularities.	Abrasive	Fatigue	Electrical processes, electro – spark, electro-erosive
5	Destruction caused by molecular irregularities fastening	Other causes like: an erosion or fatigue of surface layer	Through spalling	Process of plastic deformation	
6	Mechanical destruction caused by high temperature			Chemical reaction process - corrosion	
7				Hollowing of solid body layer surface process – erosion and cavity	
8				Destructive reaction of frictional heat	
9				Other process – other types of wear (open classification)	

Typical classifications common in literature are: Kislik [15], Zajcew [15, 6], Hruszczow [7], Barwell and Stroug [14], commonly recommended Lisowski [15] and Kostecki [6, 16]. Nevertheless the classification presented in literature [1], is described with enforcement processes segregation like: mechanical, chemical, thermal, electrical. Segregation in computer aid application is preferable (the obvious advantage, is the genesis information of a wear included in the each class description). Other wear segregations can be met in literature: mechanical, corrosive-mechanical, corrosive [14]. The diverse descriptions of a damage and destruction coexists with wear descriptions in literature [14] what directly relates to machines elements surface and elements integrity. In those relations the damage is classified as: cavitation and impact. Described wear classifications in literature are overall, and in which appears inconsistency according to: range of classes, terminology and difference in involved technical phenomenon description. For ex. in Barwell and Stroug classification, the “wear actuated with abrasive particles” corresponds to Lisowski classification in “micro-peeling process – abrasive wear” which corresponds to “mechanical process – abrasive wear” in EMME classification [1]. In Kislik classification similar assignment is problematic and ambiguous, because corresponds to other classifications, and it is described as destruction in micro scale – “mechanical destruction of coupled irregularities”. The widest classification besides of Lisowski Classification (9 classes, but it’s the open one) is the EMME classification (14 classes). The common classifications are used for specified description of elements condition, that are constantly under wear processes. In that case the wear class should be assigned as many times as needed to complete description of existent worn in a specific case. According to Barwell and Stroug the worn in consequence of corrosion (position no. 2 – Table 1) is existing in the same area with worn caused by existence and activity of abrasive particles (position no. 3 – Table 1). That set correspond to Lisowski classes: chemical reaction process – corrosion (position no. 6 – Table 1), micro-slicing process – abrasive (position no. 1 – Table 1).

3. NON STANDARDIZED COMMON DAMAGE AND DESTRUCTION CLASSIFICATIONS

According to the literature analysis the “damage” term is commonly used [5, 15] as unpredictable occurrence. Furthermore the damage term is present for ex. in description of the Weibull distribution application [5]. It is also commonly known that “damage” and “wear” terms are very often interchangeably used (cavity damage [14]).

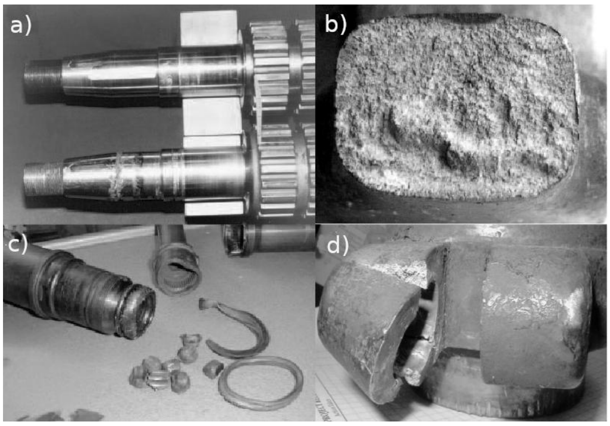


Fig. 1. a) typical ship component before and after refurbishing process, [13], b) brittle fracture surface of high stress chain, as a result of heat treating problem [3], c) yielding fracture of UH-1 helicopter engine shaft, and bearing components [3], d)ductile fracture of 2 ½ inch hose fitting- deformation and fracture [3]

The “damage” term is commonly used equivocally, but mostly with a proper meaning in vibration condition monitoring discipline [2]. The term of “damage intensity” is also considered according to situation when it appears, in the following cases, during grind–in processes or when permissible wear exceeds. Other very important examples are “methods” (nor technologies) of gear refurbishing that can be met in literature [14].

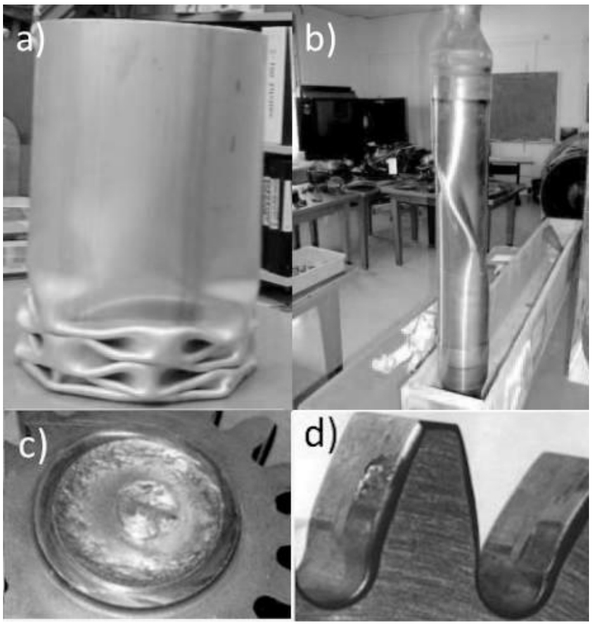


Fig. 2 a) compressive buckling failure of metal cylinder [13] b) torsional buckling failure of an F18 engine shaft [13] c) torsional low-cycle fatigue fracture of a shaft [13] d) spalling failure on the surface of a gear tooth caused by surface fatigue [3]

Author of this example [14] classifies damage character with the assignment to new or existing refurbishing technological process. This classification starts from wear of working tooth profile. In subsequent classes author describes damage character as: “chipping of teeth row on edges”, “chipping teeth of large module gears”. In this case “chipping” became a class of damage. What is more important the proper classification gives a possibility to create assignment between proper worn, damage classes and possible refurbishing technologies. Other interesting approach for description is presented as “contact wear” [1].

In this approach classes are named as follows: “plastic deformation”, “adhesive wear with possibility of braking separation occurrence”, “layer surface fatigue (pitting) with possibility of breach and cracks occurrences”. This inconsequence of nomenclature could lead to imprecise description of the element technical condition. Those descriptions should be applied in a way that precisely defines coexistence of wear and damage in technical mean, not only a possibility of damage occurrence.

More examples damages descriptions based on classification are presented in other articles [13, 3, 4]. For example, in the cited articles authors had distinguished description of the corrosion as a wear and damage appearance (exactly the “corrosion pit”). In this case it should be assumed that corrosion pit could be an independent class of damage classification. In this paper material failures are also presented like: fracture (Figure 1), fatigue, wear, corrosion. Another example of the unpredictable appearance is the yield damage, presented according to environment influence factor (Figure 1). The yield fracture is also presented as another damage description, what is presented in Figures 2 (a) and 2 (b). All cases presented in Figure 2 except Figure 2 (d), are examples of so intense damage concentration that element should be further classified as destroyed.

4. THE SOLUTION OF TECHNICAL STATE OF ELEMENT DESCRIPTION

The technical condition can be observed directly [12] or through measurements. Damage could be a result of wear process progression with exceeding of tolerance. In that case the typical damages examples are: gear shaft fracture as a result of mechanical fatigue wear, turbine cavity pits group as a result of mechanical cavity wear, global plastic deformation of piston rod as a result of unpredicted limit switch electrical circuit failure. The proposed systematized wear classification (see the Figure 3) is similar to EMME classification with the difference that: corrosion description is presented as one class (even if corrosion is caused by galvanic or chemical processes), additionally pitting is meant as one of possible fatigue mechanical wear.

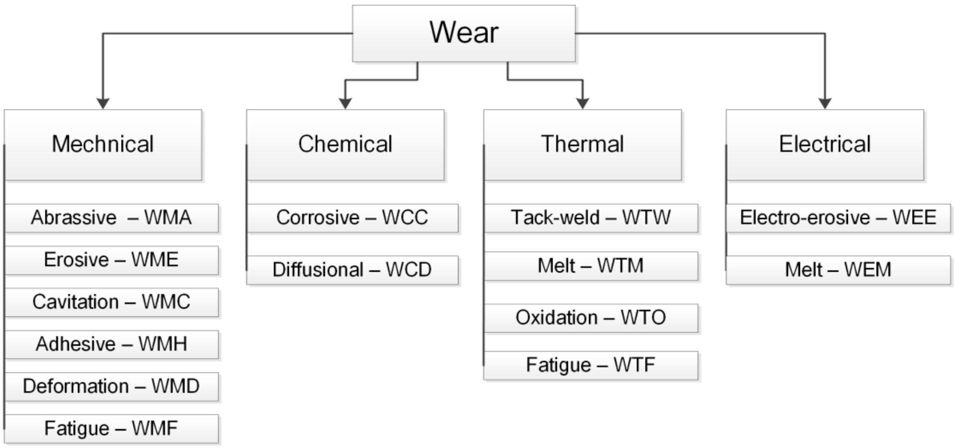
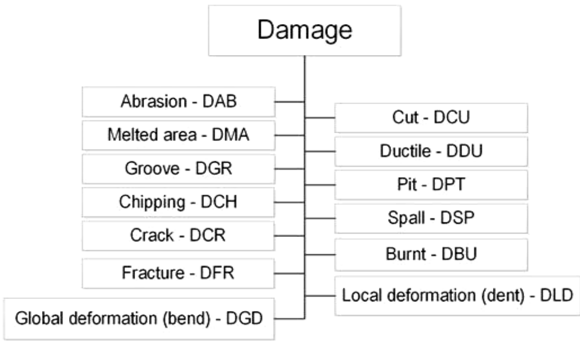


Fig. 3. Author Systematized Wear Classification (SWC) based on EMME classification with proper shortcuts assignment in order to apply in computer aid applications

Whereas tack weld is a class which has its background in the Type II tacking Kostecki’s class, and electro-spark process has its name changed to melt (local) which is caused electrically. The chemical diffusional wear is one of the new wear type (for ex.: hydrogen diffusional wear –hydrogen embrittlement [4, 17]). Shortcuts helps to manage data in database and simply fasten a readout. Most of shortcuts are taken from first letters without any doubling (in exception of mechanical adhesive wear – 3rd letter). Appearance of a new form of damage would bring a necessity of introducing into the damage classification a new class description. Furthermore presented relation between wear and damage classes brings possibility of further automation of the element technical condition description process (assign algorithm). In presented table (see the Figure 4), the DCU cut damage class does not appear, because that kind of damage occurs from unpredictable actions like: worker fault, collision as a result of end-stop switch failure, pressure pomp failure caused by overheating. Global and local deformation damages have to be described with separate classes.



No.	Worn Code	Damage Code
1	WMA	DAB, DMA, DGR
2	WME	DAB, DGR
3	WMC	DAB, DPT
4	WMH	DAB, DGR
5	WMD	DGD, DLD
6	WMF	DCH, DSP, DCR, DDU, DFR
7	WCC	DPT, DCH, DCR, DFR
8	WCD	DFR, DCR, DCH
9	WTW	DGR, DMA
10	WTM	DMA, DGR
11	WTO	DBU, DMA, DGR
12	WTF	DFR, DCR, DGD
13	WEE	DMA, DPT
14	WEM	DMA, DBU

Fig. 4. Systematized Damage Classification (SDC) with correspondent relation of damage caused by specific wear progression with acceptable wear exceeding

For example a piston rod could be deformed in this way that it axis is not linear in global manner (bend along axis that exceeds a tolerance) or locally deformed in the outer layer surface and in a specific range.

The destruction classification is determined not only by technical state of an element, but also economical aspect. Is some cases it is still possible to refurbish an element, but it would be unprofitable. The economical pragmatism should be described by other type of classification (economical evaluation). Economical profitability is being determined differently and it depends on machinery accessibility, manpower, technical means complexity, organization, transportation aspect, ecological aspect, law regulations etc. However relative cost helps in general, to evaluate approximate refurbishing profitability.

5. SOFTWARE IMPLEMENTATION AND TECHNICAL CONDITION DESCRIPTION EXAMPLES

The classification module implementation is based on the presented solution of an element technical condition description. In order to apply this description with proper assignment to a part of element, it is necessary to readout measurement result from the database. The readout data are associated with material loss appearance. The relation material loss – an element technical condition plays a key role in automation of the description process realized with suitable author's application. Such implementation is presented in the Figure 5, where material loss is presented by automatically generated map of material loss distribution [8] based on data gathered from 3D scanning [11] (3rd generation of element preparation to refurbishing process – integration of scan data and CNC generated G-code [10]). Furthermore the material loss distribution map is automatically analysed according to area detection (O_1, O_2 – Figure 5) with author's algorithm. Dimensions described as "X1" and "X2" determines the range of material loss according to Z-axis on the lathe machine tool, and that further represents the length of the shaft. Dimensions described with "D" are diameters (minimal, maximal, medium) from the detected area. The description preparation window (see the Figure 6) is based on the proposed classification with main groups of wear, damage and destruction main classes (WDDDM). As a result of the element technical condition description the proper table gathers all data (Figure 5). In this table the particular columns represent the "EPART" ID of the element being described, "AREA" the ID of the part of element area for which a material loss was detected [9], "WEAR" assigned class of wear, "DAMAGE" assigned class of damage, "COUSE" that explains the origin of damage (which could be, wear or an unpredictable occurrence) coded with proper ID and description. The last column "DESTR" allows distinguishing whether the element is destroyed or not.

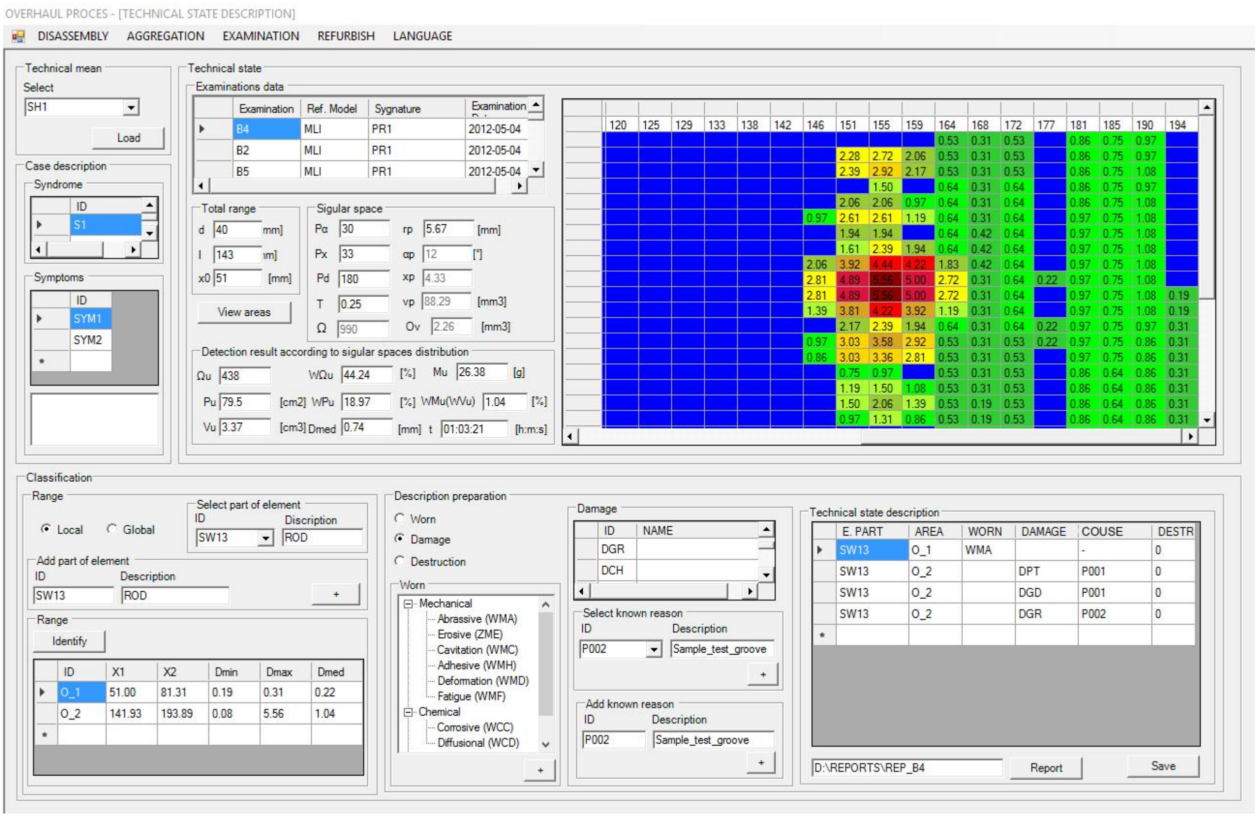


Fig. 5. Author technical state description module software – implementation of technical a condition description with the WDDDM classification and the coding

The state of the destruction is being identified for that cases when wear and damage concentration is so high that it is impossible to apply any of available refurbishing process. The technical description table, as an output of the presented software module, is reliable, precise and explicit. The proper method of the element design shape coding is important from the need of the precise determination of wear or damage placement location point of view. The first example is presented in Figure 6, where element is described with parts descriptions and coding. Technical state description could be initially prepared with high resolution and quality photographs and macro photography images for areas where additional worn presentation is needed (prepared workstation with consistent lighting). The Technical state description should be complemented with data from measurements (with a specific uncertainty). The camshaft for which, cycles quantity (equation (1)) could be estimated according to medium velocity and medium engine rpm values. In technical description Table 2 rows quantity is based on equation (2), there are total 5 rows of data that contains destruction value set to 1. The destruction in this case is dictated by economical rationality aspect. The shaft could be refurbished but the cost for it, is too high (in ex. HVOF-turning-grinding method). Furthermore it is interesting how good is the state of cam shaft steps (with one intermediate in A3 and minor chipping damages in A4, A12 areas).

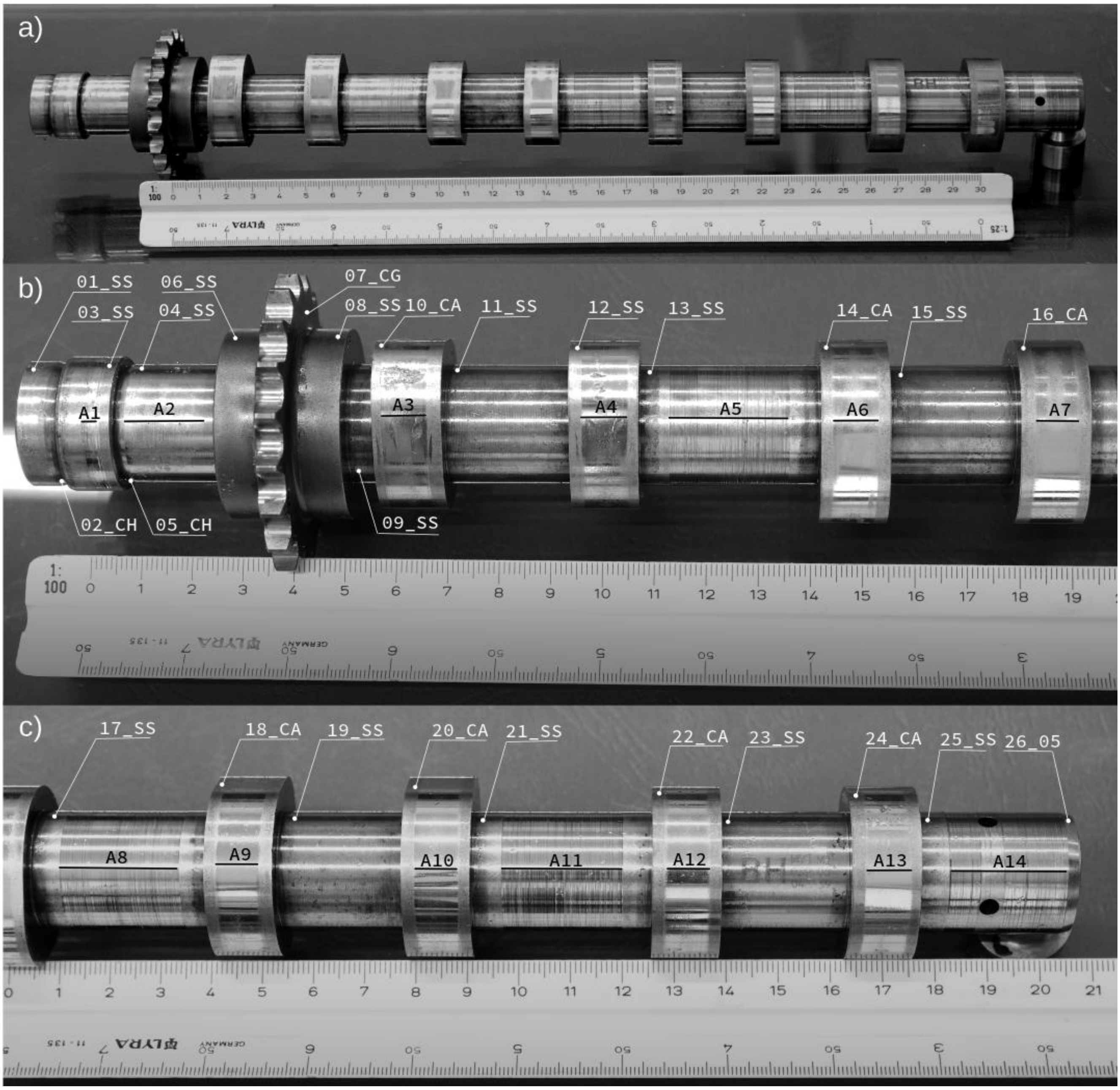


Fig. 6. Cam shaft example with specified part of elements: a) whole cam shaft, b) left side close-up (chamfers on both sides of 03_SS are omitted), c) right side close-up

$$C_q = 60 \cdot \left(\frac{T_d \cdot R_{sm}}{V_m} \right) \cdot T_e = 60 \cdot \left(\frac{180000[km] \cdot 2200[r/min]}{70[km/h]} \right) \cdot 0.5 \approx 169714286 \quad (1)$$

where:
C_q – estimated cycles quantity,
T_d – car total distance,
R_{sm} – estimated medium rotations per minute,
V_m – estimated medium velocity,
T_e – engine transmission (driver shaft – camshaft).

Besides of grooves in A5, A8, A11 and A14 areas on cam, this element could be still operational nevertheless the replacement is recommended (further damage in A3 area progression).

Table 2. The technical state description of cam shaft element

No.	El. Part	Area	Worn	Damage	Cause	Destr.
1	01_SS	A01	WMA	null	null	0
2	03_SS	A01	WMA	DGR	C01	0
3	04_SS	A02	WMA	null	null	0
4	07_CG	19T	WMA	null	null	0
5	10_CA	A03	WMA	null	null	0
6	10_CA	A03	WMF	DCH	WMF	1
7	10_CA	A03	WMF	DLD	WMF	0
8	12_CA	A04	WMA	null	null	0
9	12_CA	A04	WMF	DCH	WMF	0
10	12_CA	A04	WMF	DLD	WMF	0
11	13_SS	A05	WMA	DGR	C01	1
12	14_CA	A06	WMA	null	null	0
13	14_CA	A06	WMF	DLD	WMF	0
14	16_CA	A07	WMA	null	null	0
15	17_SS	A08	WMA	DGR	C01	1
16	18_CA	A09	WMA	null	null	0
17	18_CA	A09	WMF	DLD	WMF	0
18	20_CA	A10	WMA	null	null	0
19	21_SS	A11	WMA	DGR	C01	1
20	22_CA	A12	WMA	null	null	0
21	22_CA	A12	WMF	DCH	WMF	0
22	22_CA	A12	WMF	DLD	WMF	0
23	24_CA	A13	WMA	null	null	0
24	25_SS	A14	WMA	DGR	C01	1

Worn product could result further damage of engine and speed up mechanical abrasive worn (WMA), with particles shared in oil (if not properly filtered). The technical description could be now easily stored in data base with proper assignment of element signature. This is a unique code assigned to specific element (it is not a drawing number), but corresponds to drawing no. and/or 3D CAD model. In this way there is a possibility to store data about element for future comparison or technical condition, and future predictions. The C01 is specific code of damage appearance cause. In this case it is a lack of lubrication in specified areas. Damage cause could be widely described in database as text note. For ex. "The oil starvation symptom is caused by fell out of the hole plug from the second central camshaft (lack of oil pressure driven to both cam shafts)". The second very different example is transmission box housing – Figure 7.

Table 3. The reduced element technical state description of transmission box housing

No.	El. Part	Area	Worn	Damage	Couse	Destr.
1	01_OS	A00	WCC	null	null	0
2	03_FC	A00	WCC	null	null	0
3	05_FC	A00	WCC	null	null	0
4	06_FC	A00	WCC	null	null	0
5	08_FC	A00	WCC	null	null	0
6	09_FC	A00	WCC	null	null	0
7	11_FC	A00	WCC	null	null	0
8	12_FC	A00	WCC	null	null	0
9	18_RW	A01	WMF	null	null	0
10	31_FC	A00	WCC	null	null	0
11	32_HL	A00	WCC	null	null	0
12	33_FC	A00	WCC	null	null	0
13	34_OC	A02	WCC	null	null	0
14	35_CH	A00	WCC	null	null	0

This example shows very different approach to description with ordered selection and aggregation. That helps to distinguish: similar parts of element (i.e. threaded holes in order to fasten the covers or fixing arms with holes), parts that are used by direct or indirect contact (i.e. additional sealing element, sleeve) to assemble other element. This approach gives a proper aggregation of similar parts of element in to groups in Table 3.

$$R_n = P_n + E_d \quad (2)$$

where:

R_n – rows description set quantity.

P_n – part number (for instance: key slot, groove, shaft step, hole etc.),

E_d – quantity of extension descriptions.

Ordered selection is executed with direction from top to bottom of the housing with specific position (most of situation it is a good practice to set position as it is in higher level assembly or as in technical drawing). In Table 3 the technical description is prepared according to WDDDM and given approach for selection and aggregation. The description presents that the housing part is in good condition. Furthermore the inner cast free form surface and faces are in very good condition (oil was present in the housing before disassembly process, what preserves that surface against chemical corrosive worn. The outer rough cast surface is corroded. In order to set proper description for that surface the area is described as A00, what means that the chemical corrosion worn is distributed across that specific surface in diverse areas.

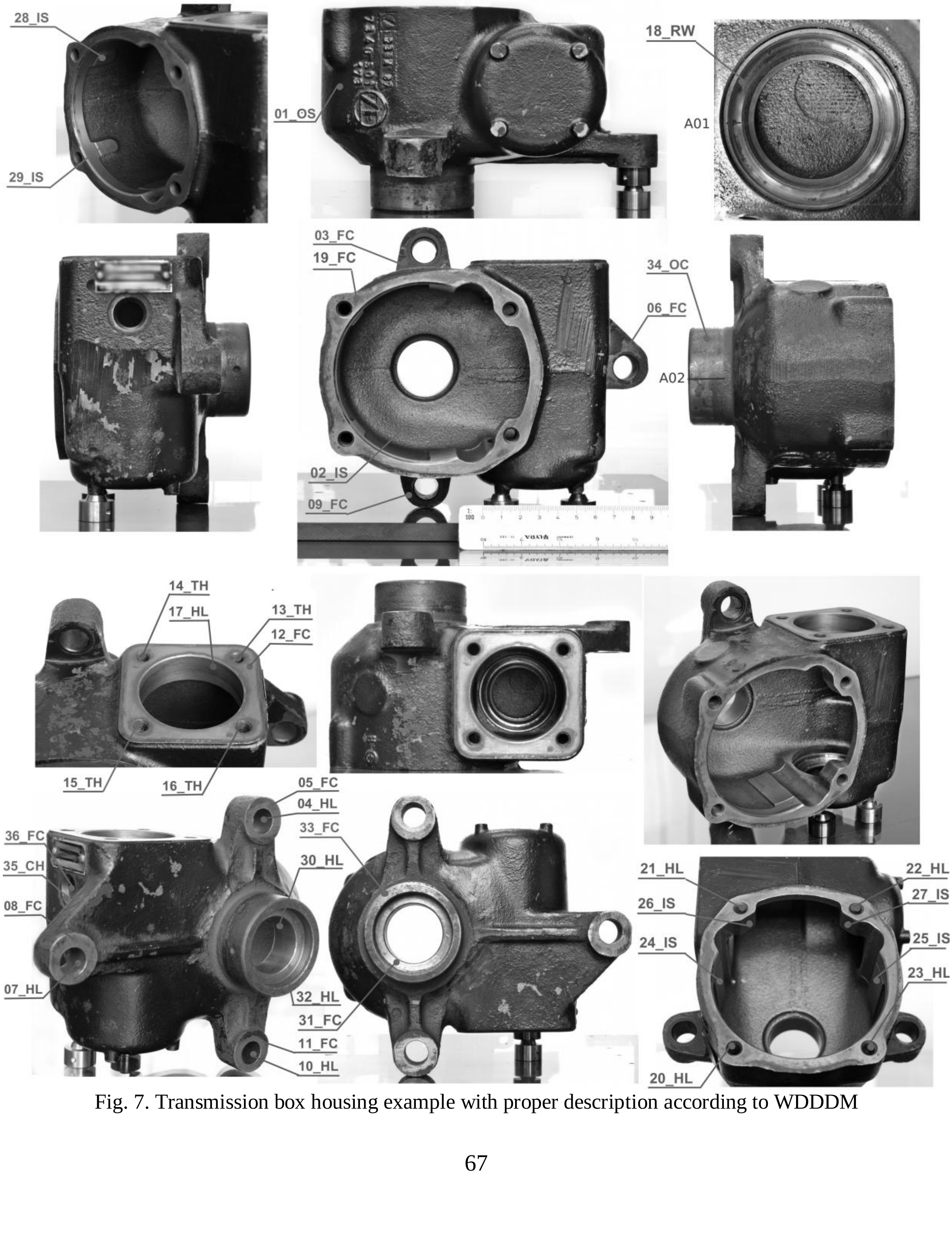


Fig. 7. Transmission box housing example with proper description according to WDDDM

Rows R_n in Table 2 is reduced according to equation (3).

$$R_n = R_n - 1, \forall null \in T_{TSD}[n,6] \quad (3)$$

where:
T_{TSD} – technical state description table,
[n,m] – [row,column], column number starts from 0.

Mentioned code is applied for more parts of housing element with exception of: pressed in bearing ring - the outer race with mechanical fatigue worn (spalling in initial state, no damages) and outer cylindrical surfaces corrosion worn with possibility of area distinguishing. The housing part could be applied again with proper cleaning and reassembly.

6. CONCLUSIONS

Machines components that works in assemblies are degrade during service time in relation to specific worn processes. Technical state of that components changes from run in, through even wear to the state that damages occurrence is more frequent, what eventually leads to destruction. Common classifications differentiate through range and used terms. Proper selection of classes is needed in order to fulfil description with wide range of possible wear types. The damage can appear form unpredictable occurrences or when permissible wear exceeds, that's why the proper relations set between wear and damage brings information of damage evaluation. This relations are never been met before in literature. With relations set, a description of technical state contain more information about element history and it technical state influence to present machine output in a work flow. Gathered data could be applied in future analysis of technical states of elements and with decision of refurbishing process reasonableness and it processing route. The maximum quantity of refurbishing processes that can be applied on a specific element is also hard to determine, but WDDDM with additional data gathered trough measurements is helpful to establish that value according to known well defined cases. The mutual order of design features results directly from the characteristic of the manufacturing process in that case a selected group of cutting processes like turning, milling, threading etc. The proposed classification should be tested in various circumstances (service environment, type of machines, size of machines and applied refurbishing technologies). The application of the solution in engineering software should accelerate description preparation and give an opportunity to fast and easy data gathering for future use. The result should be linked to results of examination, and measurements sets. The unambiguous description is helpful during taking decisions that are cost-effective and technical, because all sides of discussion knows exactly what the meaning of a decision is. The two presented very different examples are showing the possibility of WDDDM application as the universal tool. The reduction condition (equation 3) helps to eliminate redundancy in description and focus only on important data. In that aspect the complex parts like camshaft and housing are described with 24 and 14 rows of data. According to first example, the estimated cycle's quantity shows the possibility off accurate description in relation to cycles, mass of transportation payload, total distance and other measurements values of service time. This example also shows that even if element could be refurbished, the economical aspect brings damage appearance to be critical – chipping and grooves damages presented in Figure 8. In the other hand the second example presents that the housing is in good technical state, but the description brings an information about critical element pressed in that housing which is the outer bearing race – 18_RW (for simplification treated as a part of housing element).

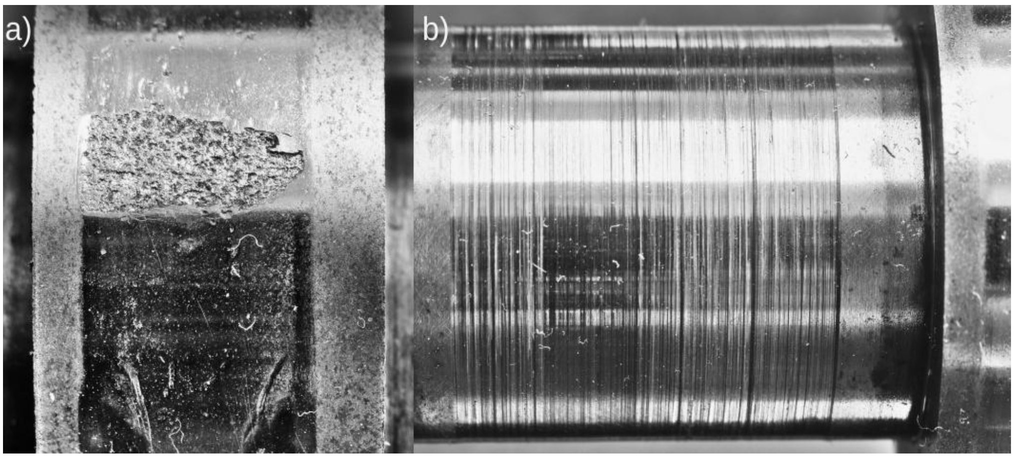


Fig. 8. Cam shaft close-up: a) visible distinguish of A03 area in 10_CA part of element and chipping damage – DCH which is the result of mechanical fatigue worn – WMF in heat treated area, b) the groove damage DGR which is a result of oil starvation (lack of lubrication – C01), similar in A5, A8, A11, A14 areas

If that race fails with spall damage in the future, the cost-effective analysis will be needed in order to determine if it is rational to refurbish that housing. The 0 ad 1 classification of destruction in cases of that analysis in that matter relates to critical set of parts that should be maintained in best possible condition.

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