Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 41
ISSUES 1-2
July-August
2010

Refurbishing technologies of hydraulic actuators applied in mining industry

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Received 09.03.2010; published in revised form 01.07.2010

Analysis and modelling

ABSTRACT

Purpose: of this paper: Mainly, future design and manufacturing processes should be oriented to refurbishing and overhaul, such as mining machines, hydraulics, military industry, heavy industry products, etc.. This paper shows method which can improve indirectly profitability also in environment protection area.
Design/methodology/approach: Methodology that solves refurbishing and overhaul problem of application, is based on CAD/CAM integration, and predicts possibility to even prepare design for refurbishing. With help of reverse engineering techniques, also exist approach to refurbish elements that has no overhaul documentation prepared before.
Findings: Preparation of overhaul documentation for families of constructions, should be computer aided with use of prepared dedicated software. Time need to prepare refurbishing technology, can be considerably reduced.
Research limitations/implications: Refurbishing and overhaul in existence cycle of product should have same rights as technology or design processes. Future development of new refurbishing technologies should be prepared in software combined with CAD/CAM modules used in advanced CAE programs.
Practical implications: Mining industry after possible initiate refurbishing methods, can extend exploit time of exerted machines. Simultaneously producers of mining machines and equipment, after bringing in design for refurbishing strategy in to production, can enhance economical profits from maintenance and service time prolongation.
Originality/value: For last twenty years no development in area of patents were noticed. That came with increase of consumption strategy progressed by produces. Presented method solves issues of materials raise in prices and relatively short time of maintenance and service time period. New workstations in industry can be created with application of the method.
Keywords: Process Systems Design; Refurbishing; Overhaul; CAD/CAM

Reference to this paper should be given in the following way:
P. Gendarz, W. Janik, Refurbishing technologies of hydraulic actuators applied in mining industry, Journal of Achievements in Materials and Manufacturing Engineering 41/1-2 (2010) 104-111.

1. Introduction

Reason of intense societies interest oriented to refurbishing is technical development and environment influence. The influence is in overall disadvantageous what cause pollution increase. Ideal situation is when recirculation of energy and material use for technical means manufacture is full. That creates possibility of natural sources spare (Fig. 1).

Because of that designed technical means should have assigned additional criteria of recycle possibilities. That is designs assignation of features, which improves properties like: durability, disassembly efficiency, recycling materials use, possibility of refurbishing and utilization. That's require a design

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methodology oriented to refurbishing, and awareness of designers improvement regard to refurbishing criteria obey. Designer stands upon deigns estimation oriented to refurbishing. Particular indicator of technical means recycle possibility is a percent mass participation of elements totally manufactured from renewable resources and refurbish assigned elements.

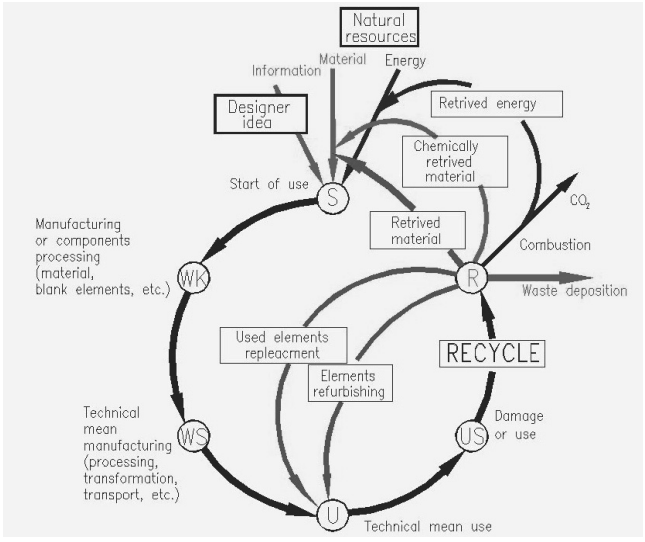

Fig. 1. Overall recirculation strategy

Main issue in this case is and refurbishing technologies development oriented to classes of technical means. Most receptivity to recycle class of technical means is a class that is based on manufacturing oriented to families of constructions.

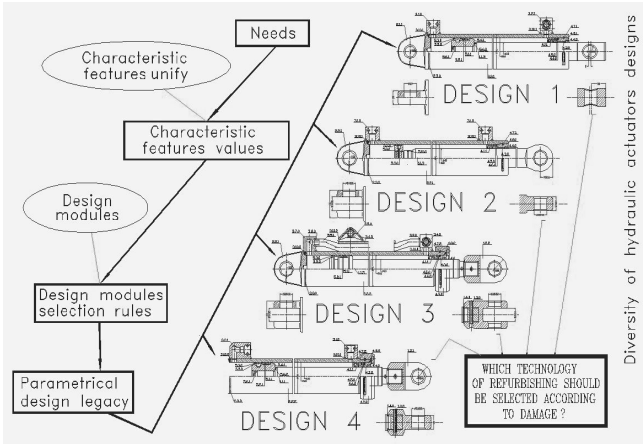

Fig. 2. Model of hydraulic actuators designs based generation with use of design modular system

Ordered family of constructions is a collection of designs with optimal features distribution, according overall system [7]. Example that kind of construction families is collection of hydraulic actuators designs created with use of hydraulic actuators design modular system [1, 4, 5]. Because of repeatability designed process routine appears possibility of computer aided not only design, and manufacturing processes but also preparation of technical documents and drawing oriented to refurbishing. On Fig. 2 where presented a model of hydraulic actuators design created with use of modular design system, and issue of refurbishing technology assignation. In target of rational refurbishing model creation there is need a knowledge of: design of technical means diversity and reasons of most common failure reasons.

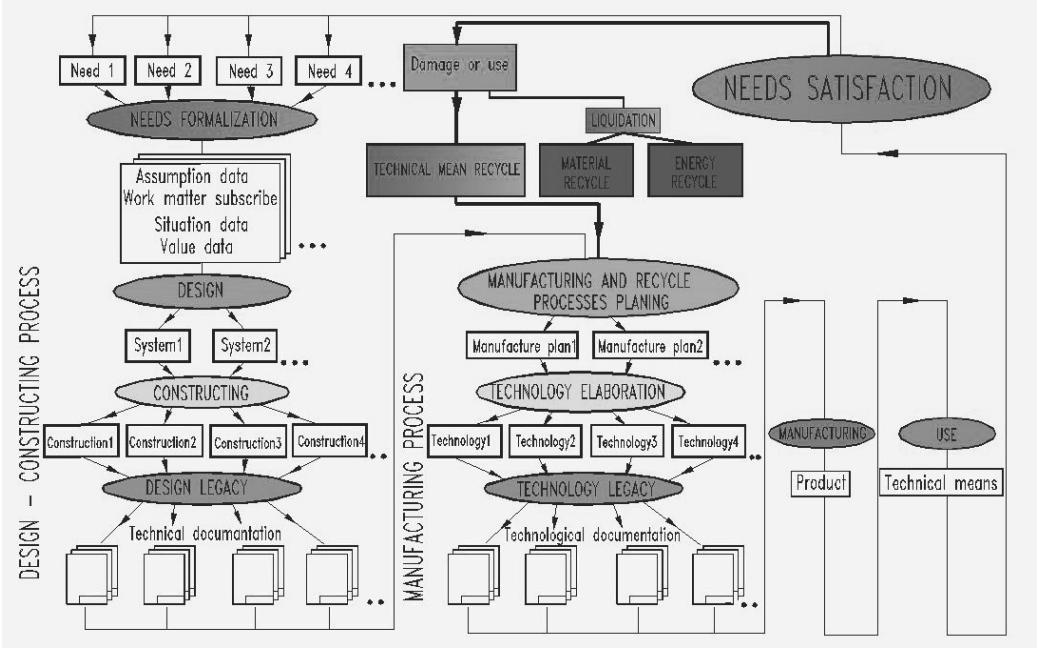

Fig. 3. Overall design process combined with manufacturing and recycle processes

2. Technical means existence cycle

In process from need to need satisfaction we can mark out following technical mean existence stages [6]. Fig. 3. Most decisions about refurbishing possibilities are made during design and manufacturing process. First outcomes of right design features selections according to refurbishing process appears during manufacturing process where production waste utilization take a place. In use process technical mean handles it's reliability according to recycle. What appears hire is most common swap or refurbishing of elements. If technical mean reveal failure or damage, decision about refurbishing or even total use retraction should made. According to selected refurbishing strategy selections can be done: Recycle of technical mean, recycle of material, recycle of energy. Recycle of technical mean is an efficiency restoration by property reconstruction based on swap or refurbishment. In marginal exception technical means is liquidated what's bound with disassembly, material selection and according to characteristics, material recycling, and energy recycling or even utilization and disposal utilization processes.

Material recycling concern all technical means existence cycle, mainly manufacturing, use, recycle and liquidation and it's bound to material retrieve to next manufacturing process. Correct material recycle can be provided with use of additional criteria: minimization of material use in technical means or elements that are common failure or damaged, production waste minimization, minimization of material use during exploit, maximal amount of renewable material use. Energy recycling concern especially manufacturing, use and utilization processes. It's depend to energy retrieve and further management. According to this main criteria should be provided: minimization of energy consumption during manufacturing process, minimum energy consumption during use of technical mean and material use with possibility of energy retrieve (e.g. incineration).

2.1. Main recycle criteria and recommendations

In case of technical means optimization according to recycle selected criteria arrangement can be used. According to the practical researches main criteria were selected:

- Low technical means complexity,
- Maximal amount of normalized and catalogue elements,
- High durability,
- Minimum diversification of material used in technical means,
- Maximum renewable materials used in technical means,
- Minimal mass of swapped elements,
- Minimum quantity of disassembly operations,
- Minimal quantity of disassembly tools,
- Easy access to swap elements,
- Minimum joints quantity,
- Minimum joints diversity,
- Minimal quantity of welded elements,
- Maximum quantity of easy make away joints, and halt elements,
- Maximum quantity of elements used in technical mean protected against rust,
- Provide damage and failure protection,
- Simple sort of elements,
- Minimum manufacturing cost according to durability,
- Minimal recycle cost.

Beside of criteria recommendations can be also assigned like:

- Use kind of hierarchical structure that gave a possibility to disassembly in order: assemblies, subassemblies, and elements,
- Use of ordered designs families (series of elements, modular design systems) design features diversity optimization,
- Assign element features, that it not influence design of cooperative elements in refurbishing process,
- Documentation preparation with use of CAD,
- Provide parameterizations of elements,
- Provide selection of common failure and used elements,
- Provide protection against further failures and damage,
- Elements exposed to damage should be analyzed with FEM method,
- Assign material features to tension and deformation,
- Provide greases use that makes disassembly easier (e.g. graphite grease),
- Provide materials with interaction tolerance,
- Provide minimum waste technology,
- Provide recycle manufacturing waste to production process,
- Provide intellectual simulation of disassembly,
- Prepare initiative project of recycle.

Presented criteria and recommendations provide rational direction of technical mean designing where in the hydraulic actuators modular system:

- Piston design diversion where reduced from 58 to 6 possible solutions,
- Characteristic features were ordered to 20 unified needs and any travel value selection according to criteria selected range,
- Only one type of sealing where used and one type of lead bearing as well on the piston and on throttle element
- All element where unified and most commonly swapped by normalized/catalogue elements.

Provided design solutions characterize with disassembly simplicity (Fig. 4a), Refurbishing process were predicted for elements especially like tube and pistons, Design were adapt to provide simple disassembly, and protection to operating range surface preservation, Operating range surfaces were protected with use of: DURACHROM coating, graphite grease coating provided of static operative surfaces, thread joints sealed with Loctite glue according also to provide thread joint from unscrewing, Material diversity reduction (e.g. elimination of bronze bushings, and replace with steel bushings with leading bearing made from poliacetal. Only renewable materials were used. Elements commonly damaged were analyzed geometrically and with FEM. Type-values of leading bearings, sealing bearings, resistance bearings, gather bearings ("O" shape), were determined for hydraulic actuators applied for mining industry. Those elements were manufactured by specialized producer. As an example, Fig. 4. represents design of hydraulic actuator created with use of hydraulic actuators modular system.

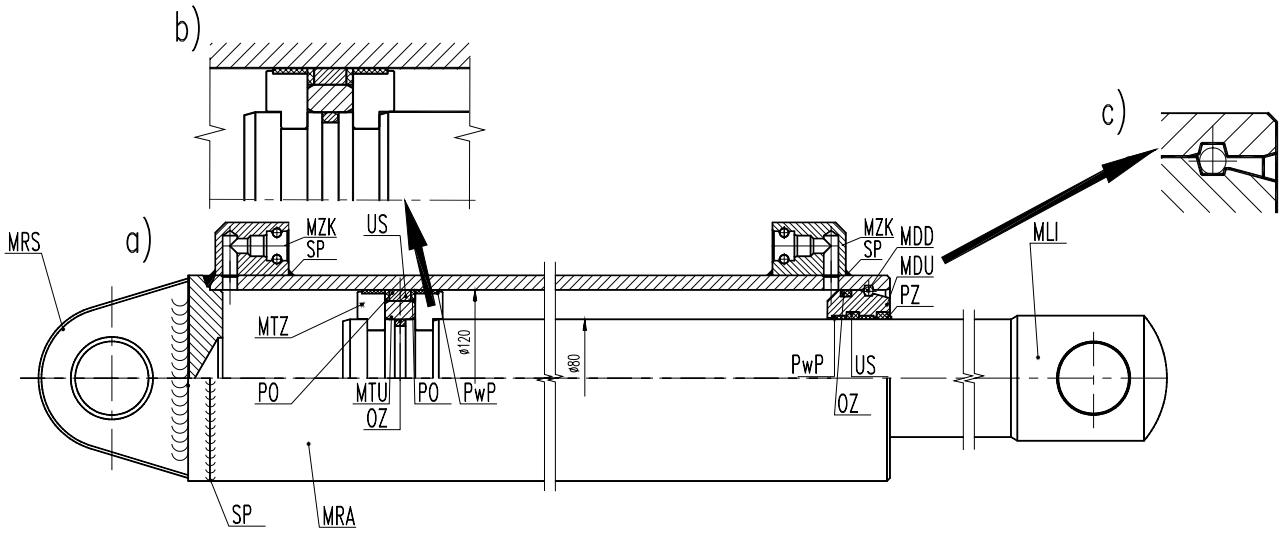

Fig. 4. Hydraulic actuator design generated with use of modular system program [5, 8]

Key to rational recycling of technical means is a simplicity of most common used or failure elements disassembly. As an example views Fig. 4b. where after piston is pull out from tube element piston is disassembled instantly, because of provided MTZ and PWP composed bearings. Disassembly of throttle element presented in Fig. 4c. is also easy because of provided wire connection. Threaded joints in aggressive mine environment cannot be treated as separated joint because disassembly in this case is impossible without causing a damage.

3. Technical means recycling, based on hydraulic actuators example

Recycling strategy selection is a subject of optimization. Group of solutions are recycling strategies. For example will be presented a braking pad [3]. When grind layer is used, should we replace used grind layer with new one? Another option is to melt all Romains elements end recycle material. For example washing machines energy consumption is minimized nearly 55% and water consumption nearly 48%, as a result recycle of old washing machines which energy consumption is high is ecologically. Also for a proper selection of recycle strategy cost count should be made [12]. In overall look use costs with recycle costs should be less than manufacturing costs (Fig. 5.). Because of market concurrency lots of companies decided to provide recycling. Leading companies in this particular enterprise are Deimler Benz, MBW and Siemens Nixdorf Informationssysteme [2]. In last presented company strategy of recycling contains three degrees of refurbishing (oriented to logic circuits):

- reuse of elements in new products,
- elements refurbishing,
- material retrieve.

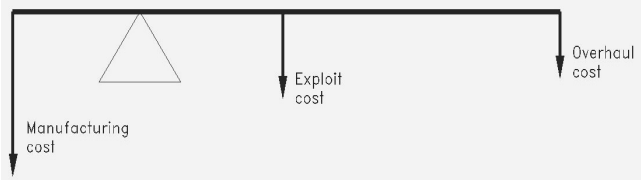

Fig. 5. Model of cost balance what decide about technical mean recycle [9, 14]

As an positive effect of such strategy manufacturing waste were reduced from 65% in 2000 to 20% in 2003, calculations were based on used technical means total mass per year [2]. Basis recommendation according to presented examples is that all producers which manufacture specified class of technical means should also provide recycle for those technical means. Most effective in recycle will be this technical means class that will which basis of design and manufacturing is a ordered family of designs [7, 12, 13, 15, 16] and technology, according to provided repeatable elements and technological processes and recycle. Factor which has an influence is an hierarchical system structure of technical mean which are: assemblies, subassemblies, elements [10]. This structure is relative to system of technical mean, so relative connections and conversions in technical mean. Example of hierarchical structure of hydraulic actuator is presented in Fig. 6 according to technical drawing in Fig. 4a.

This particular legacy is not quite useful according to recycle, because about element replacement or refurbishing decides: System structure, but more precisely selected connections relations between two cooperative elements.

Mass of total elements quantity in technical mean, provided material, manufacturing cost. As a solution recycle graph were created $\mathrm{GR}\left\langle \Pi_{\mathrm{rw}}^{\mathrm{te}_j} \right\rangle$, which contains all important influences, Fig. 7.

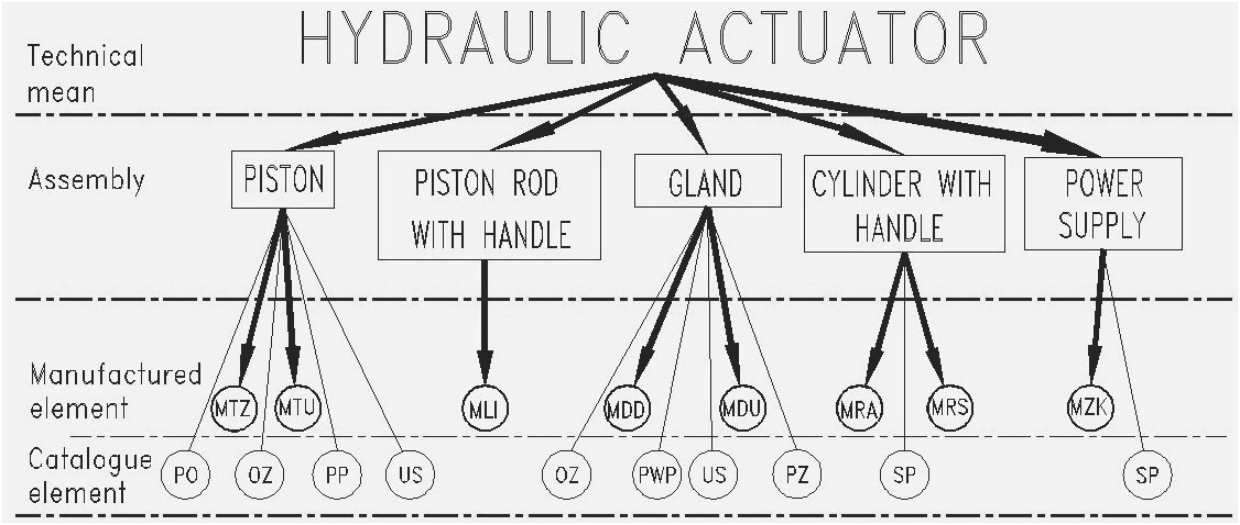

Fig. 6. Legacy of hydraulic actuator system structure based on technical drawing presented in Fig. 4a

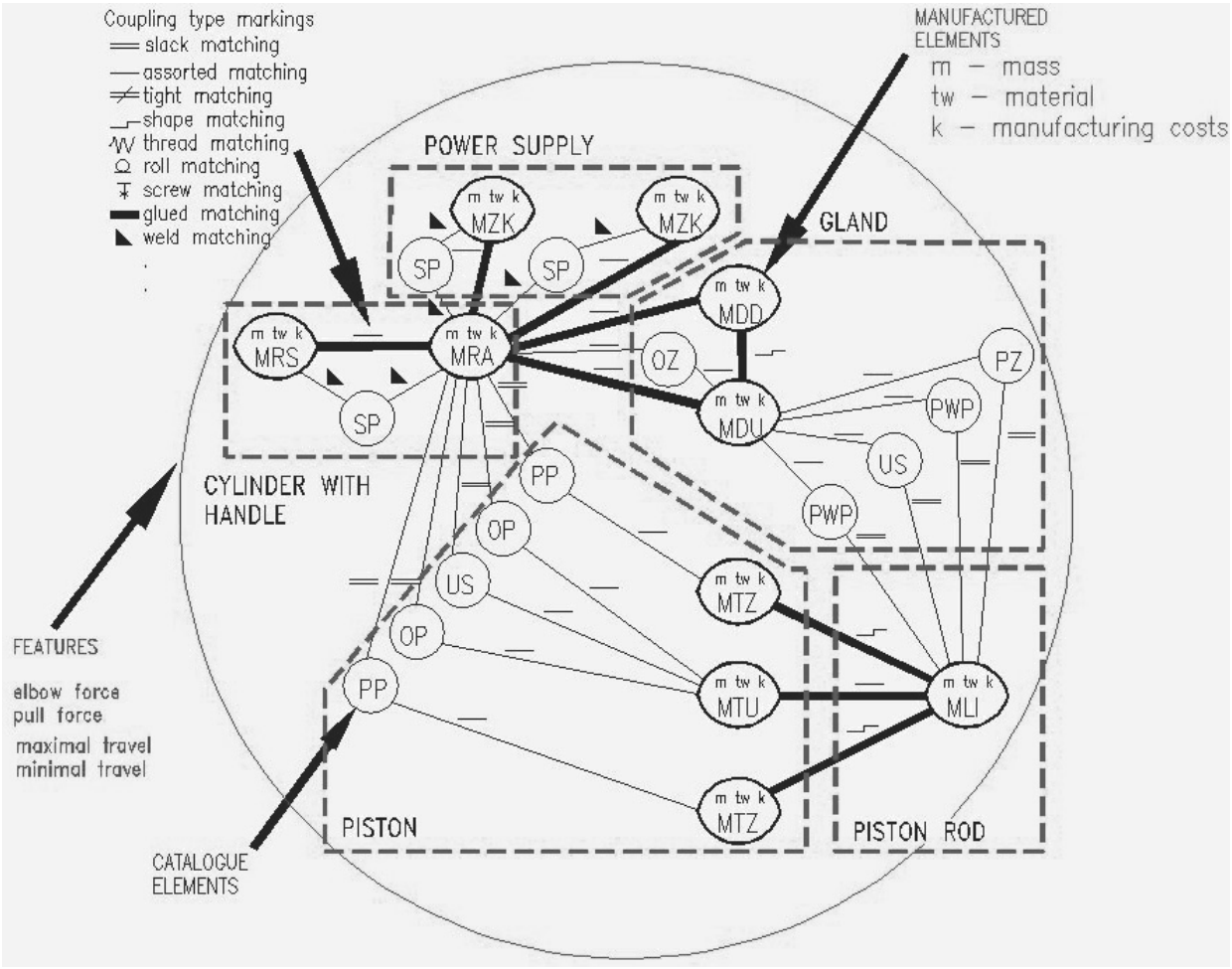

Fig. 7. Example recycle graph $\mathrm{GR}\left\langle \Pi_{\mathrm{rw}}^{\mathrm{te}_j} \right\rangle$ which is based on technical drawing presented in Fig. 4a

Technical mean structure legacy as recycle graph $GR\left\langle \Pi_{rw}^{te_j} \right\rangle$ gives possibilities of overall analysis in recycle plans PR_n. In this graph each node represents elements designs (circle shape according to catalogue element, and ellipse shape to manufactured element), and line between elements represents relative connections between to cooperated elements, additionally signed by connection type symbol (Fig. 7). Refurbishing or elements replacement is determined by criteria what is based on recycle graph, where additional information like: mass, material, and manufacturing cost are showed according to all elements in technical mean. Elements chosen to refurbish characterize great mass and large manufacturing costs. All rest elements are assigned to replacement, and according to material that were used to manufacture them to specify material and energy recycling process. To provide correct plan of recycle technical mean process, registered information about damage and failure were used and also frequency of their appear ν_u^R. Those information should be gathered, especially in recycle and manufacturing facilities, what provide to new or modified designs solutions. In hydraulic actuators used in mining industry following damages were distinguished:

UI Tightness loss in case of piston outer operating range surface corrosion etched into material at specified depth;
UII Tightness loss in case of main cylinder inner operating range surface corrosion etched into material at specified depth;
UIII Tightness loss in case of tight bearing damage on piston outer operating range surface;
UIV Tightness loss in case of tight bearing damage on main cylinder inner operating range surface;
UV Permanent piston deformation;
UVI Piston handle damage;
UVII Piston handle rapture;
UVIII Piston handle damage at fond area;
UIX Hydraulic power supply system failure;
UX Main cylinder fracture or permanent damage;
UXI Piston damage on outer operating range surface, at depth greater than 1.2 [mm] and what is classified to third degree of refurbishing process;
UXII Main cylinder damage on inner operating range surface, at depth greater than 1.2 [mm] and what is classified to third degree of refurbishing process.

Presented damages types (collected from overhaul facilities), are sorted from UI to UXII according to appears frequency. Each damage has an assigned strategy of refurbishing coordinated with overhaul facilities. Overall strategies of refurbishing are:

UI	piston refurbishing,
UII	main cylinder refurbishing,
UIII, UIX and UXI	element replacement,
UX and UXII	hydraulic actuator liquidation.

In practice could also appear complex damages, which recycle process strategy is a sum of selected strategies. Provided recycle graph $GR\left\langle \Pi_{rw}^{te_j} \right\rangle$ gives a possibility of relation selection between damage and element replacement or refurbishing.

$$uk_u \xrightarrow{PR_n} \{e_j;(j=1,jr)\} \quad (1)$$

In Figs. 8a, 8c, 8d, (where examples of this relations legacy are presented) an damage appears which influence important element replacement according to mass and manufacturing costs (Figs. 8a and 8c - pistons, Fig. 8d - main cylinder). In base of prepared technologies refurbishment of elements can be made. Most common damage of hydraulic actuators used in mining industry is an corrosion etched operating range surfaces. For elements with that kind of damage refurbishment three degree scale technology and DURACHROM technology can be applied. DURACHROM technology depend on metal chromium sheet coating (thickness about 0.75 [mm] up to Ø160 [mm] diameter and above, up to 1.2 [mm]). This sheet coating is welded by a laser to genuine element part. Basis of hydraulic actuators recycle study is an advisory program which cooperate with CAD application. This program for designs created with use of modular design system and type of damage, is generating hydraulic actuators refurbishment documentation.

Advisory program contains bundle of GENREC programs. Bundle contains:

- Design and characteristic features of hydraulic actuator identification program (ZLOREC.LSP),
- Damage type selection management program (USZ.LSP),
- Refurbishing type selection management program (RECYC.LSP),
- Quantity design features selection in their verification program, (program written in FORTRAN v.5.1 programming language, program bundle GENSIL v. 5),
- Parametric files of hydraulic actuators assembly technical drawings(111.LSP - 550.LSP),
- Parametric files of elements technical drawings (MTA.LSP, MTB.LSP.....).

Overall schema of advisory system example is presented on Fig. 9. This schema contains path from damaged element to assigned refurbishing documentation.

Stages of computer aided actuators refurbishing were distinguished:

- Characteristic features and design of actuator reconstruction,
- Type of damage selection (from UI - UXII, for UI and UII corrosion etched into depth input need),
- Replacement and refurbishing element selection,
- Provide calculations of quantity design features and geometrical and stress verification (this stage appears when design features change as refurbishing result),
- Technical drawing of assemblies,
- Technical drawing of elements (replaceable, liquidated and refurbished),
- Legacy of recycle report.

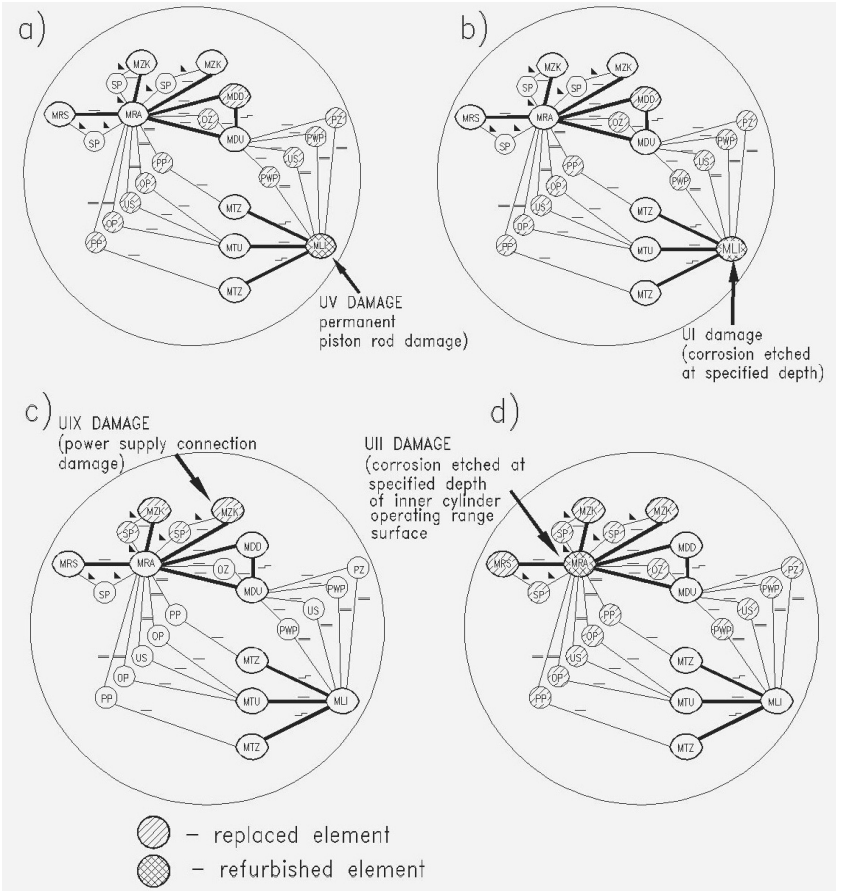

Fig. 8. Relations between damage type and element replacement or refurbishing model

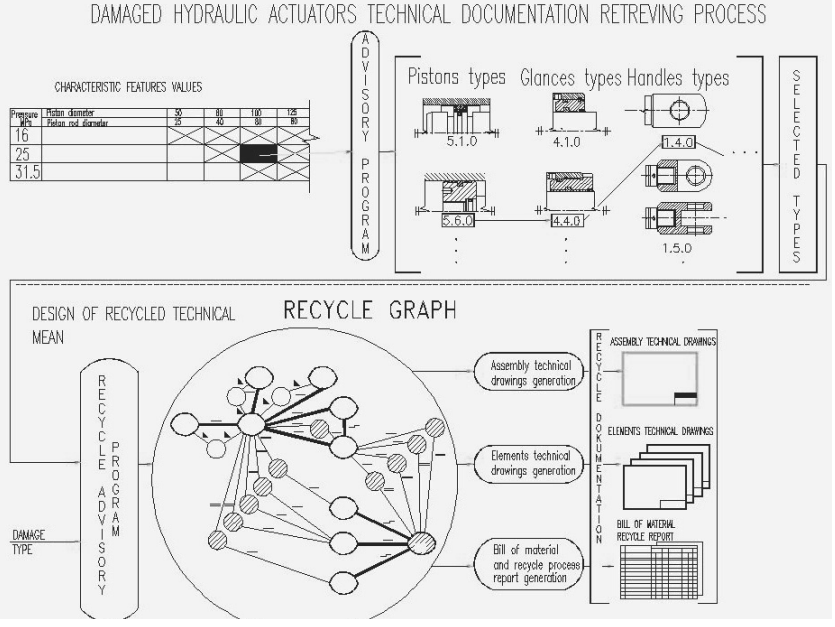

Fig. 9. Technical means recycle advisory program schema

4. Conclusions

Develop of refurbishing technologies is a need of national economy market, in which competition exacts minimization technical means use costs. Especially technical means that has huge regime work in difficult conditions e.g. hydraulic bays applied in mining industry. Thanks to the efficient refurbishing methods, which target is design oriented to refurbishing, and technologies preparation assigned to predicted failures of technical means, cost of mining industry technical means exploit decrease and simultaneously decreases cost of coal output.

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