One method for life time estimation of a bucket wheel machine for coal moving

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Abstract. Rehabilitation of outdated equipment with lifetime expired, or in the ultimate life period, together with high cost investments for their replacement, makes rational the efforts made to extend their life. Rehabilitation involves checking operational safety based on relevant expertise of metal structures supporting effective resistance and assessing the residual lifetime. The bucket wheel machine for coal constitute basic machine within deposits of coal of power plants. The estimate of remaining life can be done by checking the loading on the most stressed subassembly by Finite Element Analysis on a welding detail. The paper presents step-by-step the method of calculus applied in order to establishing the residual lifetime of a bucket wheel machine for coal moving using non-destructive methods of study (fatigue cracking analysis + FEA). In order to establish the actual state of machine and areas subject to study, was done FEA of this mining equipment, performed on the geometric model of mechanical analyzed structures, with powerful CAD/FEA programs. By applying the method it can be calculated residual lifetime, by extending the results from the most stressed area of the equipment to the entire machine, and thus saving time and money from expensive replacements.

1. Introduction

Metal fatigue is a process that produces premature rupture or damage of parts subject to repetitive stress. Fatigue is the predominant mode of loss of structural integrity, important both in occure frequency and as the decisive factor in determining the stresses on work pieces subject to variable load.

The existence of complex machinery with lifetime expired, or in the last period of operation, as well as high cost of investment to replace them, make rational rehabilitation to extend their life.

The bucket wheel coal machine with drum shedder, figure 1, is the basic machine in coal deposits of power stations or in mineral deposits within the steelworks.

In figure 1:
1- drum shedder;
2- drum shedder arm;
3- thrusts;
4- mast;
5- cable to lift / lower arm drum shedder;
6- apparatus box / counterweights;
7- tilted arm;
8- rotating platform;
9- tripod support;
10- translational mechanism;
11- machine rolling way.
Fig. 1. Bucket wheel coal machine.

Designed after KSS model - East German, these equipments were assimilated for different work situations in the Energetic complexes or mineral deposits, with work capacities necessary to technological flow used, with wheel arm shedder of different length or different cups capacity.

2. Structural analysis of bearing structure

For structural rehabilitation of the machine is performed the technical expertise of the entire technological equipment, both bearing structure and the main mechanisms that can affect the safety of the equipment, in order to determine the approximate remaining duration of life.

The most vulnerable points are the points where welded elements are subject to cyclic loads. In machinery from coal deposits the tie rod arm for lifting shedder wheel (figure 1, item 3) is continuously subjected to variable loads. Besides performing lift-lowering arm, it takes lateral forces and tensions generated by the massive cutting when machine is turning left / right.

Load value for calculation for determining residual lifetime duration is given by [1], which determines an equivalent dynamic force, derived from static loads, denoted by $P_{dyn}$ established with the relationship:

$$P_{dyn} = \pm \psi \cdot \sum P$$  \hspace{1cm} (1)

where:

$\psi = 0.10$ - dynamic load factor for machines with rotor;

$\sum P$ - The sum of all uploads oriented vertically.

It is considered a simplified model of wheel arm shedder, figure 2, which during the process of excavation execute a circular path. In figure 2: C0 – center of rotation for mobile subassembly; C1 – arm center of rotation; Deccr – distance between rotation centers; $\alpha_{rot}$ - rotation angle bucket wheel arm; $S_{AB}$ – circle arc between point A and B; BC – excavation block; Rcr – maximum radius for bucket wheel arm; Rrot – bucket wheel radius.
Figure 2. Simplified geometric model arm - wheel:
1- shedder wheel; 2 shedder wheel arm.

During the cutting process (excavation), there are the following stages of work on the cycles of operation (denoted LC 1 ... LC n) each having a working range t [s], according to figure 3 [2]:
- LC1 - entering rotor in material, during entry / exit from the working area;
- LC2 - cutting material, through space $S_{AB}$, from point $A \rightarrow B$;
- Repositioning rotor;
- Cutting the material in the opposite direction $B \rightarrow A$

Figure 3. Excavation work cycles chart.

In figure 3:
- t1 - time for positioning / repositioning at the end of the interval;
- t2 - time to walk the work path $S_{AB}$.

Next are taken following steps:
1. Determination of number of operating cycles n [cycles / year], depending on the number of hours from putting into operation;
2. The calculation of the maximum stress $\Delta s_i$ [N/mm$^2$], can be done by modelling the structure of most stressed subassembly (figure 4a), for which in figure 4b can be seen a detail, establishing the loads (figure 5) and performing FEA; From figure 6 it can be observed that the maximum stress $\Delta s_i$ occurs in welding area of thrusts and head clamp ear of arm head (detail - figure 7).

![Figure 4](image.png)

**Figure 4.** (a) Geometric model of bearing structure; (b) Clamping area thrusts-ear.

![Figure 5](image.png)

**Figure 5.** Establishing the loads.
Figure 6. Maximum stress distribution (1) – joint of clamping arm; (2) - thrusts; (3) – grip ear.

Figure 7. Detail of maximum stress area.

Elements used to mesh structure modelled, for best discretization [3] in figure 4 are:
- type plate with thickness equal to the project;
- 3D solids – tetrahedral, assigned to assembly between thrusts and ladder ear, (figure4b)

Total items for mesh: 145712 elements and 75148 nodes were created. The mass difference between the mass of structural elements according to the documentation and produced by meshing is 1%.

From finite element analysis (FEA) in the clamping area thrusts-ear was determined a value of stress $\Delta s_l = 78$ N / mm$^2$, as the maximum stress in considered area.

3. Establishing stressed welding details is done in accordance with [4] and [5], depending on the welding process and report between filler material / welded materials.
4. The number of working cycles for welding detail considered is $N_i(\Delta \sigma_i)$, according to [6]:

$$N_i(\Delta \sigma_i) = 2 \cdot 10^6 \cdot \left[ \frac{\Delta \sigma_i / \gamma_{MF}}{\gamma_{EF} \cdot \Delta \sigma_i} \right]^3 \text{cycles} \quad (2)$$

where:

- $\gamma_{EF}$ - partial factor for stress domain with constant amplitude;
- $\gamma_{MF}$ - partial factor for fatigue strength for $\Delta \sigma_i$ domains;
- $\Delta \sigma_i$ - reference fatigue resistance for welding detail considered, according to [6]

5. Depreciation or degradation factor $D_i$, for lifetime of equipment, is the ratio of the total number of cycles, $n_{tot}$ [cycles / year], during the operation, and the number of cycles of solicitation of welding detail considered [cycles], which must be subunitary [7]:

$$D_i = \frac{n_{tot}}{N_i(\Delta \sigma_i)} < 1 \quad (3)$$

6. Establishing the remaining duration of life $T_{RFL}$:

$$T_{RFL} = \frac{N_i(\Delta \sigma_i)}{n_{tot}} \text{ years} \quad (4)$$

In determining the remaining lifetime are taken into account supplementary visual inspection but also eventually mechanical testing, chemical and metallographic analysis.

3. Numerical results

Based on the steps described above will be calculated the remaining lifetime of the coal bucket wheel machine from SE Turceni, equipment totally rehabilitated in 2010.

3.1 Characteristics – input data

- Name of equipment: Coal Bucket Wheel Machine T2052-78 / d-00
- Manufacturer: I.C.P.M.R.T.U-Timisoara, Romania;
- Date of first commissioning: 1988;
- Number of operating hours: average 7500 hours;
- Hours actually worked = 18 [h / day];
- Working days = 360 [days / year];
- Drum shedder arm rotation speed = 10 m / min;
- Shedder wheel arm length = 23.25 [m];
- Maximum rotation angle = 70 degrees - the angle performed to take over the coal from stack of coal and deposition to conveyor belt;
- $\Delta \sigma_i = 78 \text{ [N/mm}^2\text{]}$ - determined by FEA in the clamping area ear-thrusts.

3.2 Numerical calculus

1. Determination of the number of cycles performed by the machine during work time performed:

$$n = 5.1 \times 10^4 \text{ [cycles]} \quad (5)$$

2. Determination of maximum stress $\Delta \sigma_i = 78 \text{ [N/mm}^2\text{]}$ in welded area - determined by finite element method;
3. Setting welding admissible stress in welding detail most stressed is determined in accordance with DIN 22261-2 / 1997 [1]

\[
\Delta \sigma_c = 125 \text{ [N / mm}^2]\]

(6)

4. The number of cycles of solicitation of welding detail considered:

\[
N_{(\Delta \sigma_i)} = 2 \cdot 10^6 \cdot \left( \frac{\Delta \sigma_c / \gamma_{Mf}}{\gamma_{Ff} \cdot \Delta \sigma_i} \right)^3 = 3.36 \cdot 10^6
\]

(7)

The values of variables: \(\gamma_{Ff} = 1.0; \gamma_{Mf} = 1.35\) are selected according to EN 1993-1-9 [6].

5. Degradation \(D_d\), during work time, in accordance with the total number of hours of operation, which occurred on service intervals under the influence of stresses \(\Delta \sigma_i\) is given by the ratio: \(D_d = \Sigma (n_{\text{number of cycles on work period}} / N_{\text{Number of cycles of solicitation}})\) which must be below \(<1\).

\[D_d = 0.13\]

(8)

Degradation factor represents the amount consumed from the lifetime of the structure, a factor of 0.13 indicating that 13% of the life of the structure is consumed; fatigue failure occurs for a wear factor equal to unity (theory ignores the effects of succession of cycles applied).

In conclusion remaining percentage of the lifetime \(T_{CR,\text{tot}}\) after completion of the some \(n\) cycles of operation is:

\[T_{CR,\text{tot}} = 0.86\]

(9)

6. Duration of residual remaining lifetime for the area considered and implicitly for all equipment - \(T_{RFL}\) [years] - remaining fatigue life, according to [6] is:

\[T_{RFL,\text{tot}} = \text{approximately 6.6 years}\]

(10)

4. Conclusions

Since the bucket wheel machine for coal constitute the basic machine within deposits of coal of power plants, makes rational the efforts made to extend their life, regarding also high cost investments for their replacement. Rehabilitation involves checking operational safety based on relevant expertise of metal structures supporting effective resistance and assessing the residual lifetime.

This study can be performed on the CAD model of the equipment using FEM as a first stage. It has to be underlined that for proper results one must carry a proper CAD model for the study, followed by a carefully meshing of the structure prior to FEA.

Finite Element Method is an easy-to-apply method in estimating the lifetime of a machine, mainly by establishing stresses for strong stressed areas [8]. Further more, in extreme stressed areas can be used refined discretization in areas with welded elements and using mixed discretization between 3D solid elements and 2D elements (plane type), but also elements of "rigid link" type for the contact with welded elements.

This analysis gives information on the state of tensions and deformation of studied structure, with good approximation, but carefully using a correct mesh and proper arrangement of bearing loads and support conditions.

By FEA it can establish the sampling areas for eventually destructive material tests along with areas for visual control and non-destructive control such as ultrasounds and penetrating liquids.

For establishing the remaining lifetime of the equipment, the method must be corroborated with break mechanical methods, as described in [9] or tensometry analysis.

By applying the method described it can be calculated residual lifetime, by extending the results from the most stressed area of the equipment to the entire machine, and thus saving time and money from expensive replacements.
5. References

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