Bucket wheel excavators: past to present experiences in safety operation

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Abstract: In Polish open pit mining there were and exist now 124 machines of 46 different types including: excavators and spreaders. After World War II it was observed 235 breakdowns and 38 of which were classified as major catastrophes related to 95 machines. Undesired events had both design and operational causes. Total number of multiple failures caused by five structural units reaches 205. Another 30 failures had operational and environmental causes. Each of 235 catastrophes was followed by official penetrating inquiry looking for basic causes. Results of investigations were introduced in design process, modernizations and regulations regarding safety operation and maintenance. Cost analysis shows that modernization or rebuilding of failed machine could be even twice cheaper than building a new one. Objective of the paper is to present closed chain of taking knowledge and data from current operation and applying it in the design and modernization process. In the paper there are historical data shown and analysis about catastrophes. Examples of included conclusions and recommendations from catastrophes of open pit mining machines in design and operation show progress in that branch of industry.

Keywords: open pit mine machine, failure, catastrophe, safety

1. INTRODUCTION AND BACKGROUND OF OPEN PIT MINING. ELECTRICAL ENERGY PRODUCTION AND MARKET.

Braun coal deposits are exploited using one of the largest in the world machines of high efficiency, high durability and high initial cost. Faults of these machines may affect as well energy production as supply of heat source. Machines have various structures, various driving and working systems and work usually in unstable conditions. Historical overview of accidents in open pit mining industry shows many catastrophes and less dangerous events influencing machines availability and safety.
Electrical energy is produced in the world in several ways and the distribution of energy sources is shown in the Fig. 1. It is also seen from historical data that domination of different energy sources changes according to technology, geography and political regulations [2].

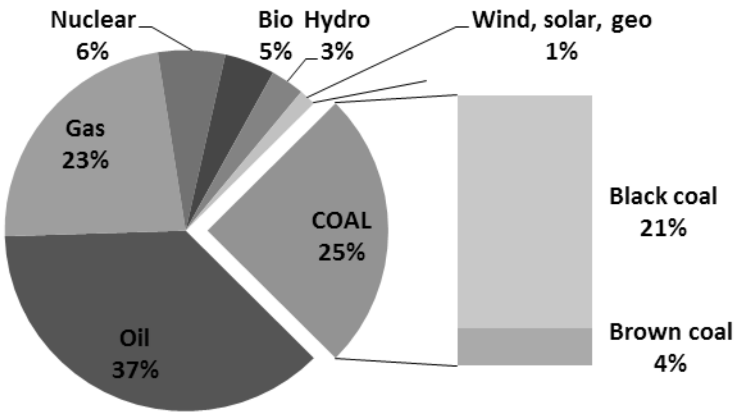

Figure 1. Approximate distribution of energy sources in the world market

It is also expected 56% growth of energy consumption within the next 30 years but still conventional, fossil fuels will be main energy sources. 80% of fuels are oil, gas and coal. Polish energetic market strongly depends on coal and brown coal has growing ratio comparing to traditional black coal. Electrical energy produced of brown coal makes 34% of total electricity while energy made of black coal is 44%. Brown coal mining in Poland exceeds 60 *106Mg what makes 5% of world mining, while Germany mines reached 17% of world mining (24% of electrical energy) as in the year 2011 [3].

2. MACHINES AND MINING TECHNOLOGY

Brown coal mining in Poland is based nowadays on four open pit mines distributed over mid-west part of Poland. Since the beginning of mine operation they produced: Bełchatów (881*106 Mg), Turów (861*106 Mg), Konin (552*106 Mg) and Adamów (187*106 Mg) of brown coal (Fig. 2) [3].

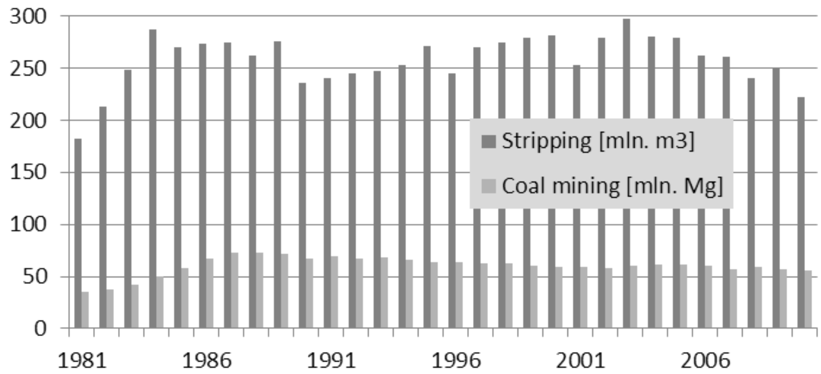

Figure 2. Stripping and brown coal excavation in Polish mines

All mines are located close to power stations and coal is transported directly from open cast to storage yard at power station by the mean of conveyor systems. Important factor in brown coal mining takes geological factors where the measure of mining efficiency is a ratio of overlay (stripping) measured usually in m3 to amount of coal (in Mg) which in Polish mines is kept approximately on the stable level of 3,6 m3 of stripping per each 1 Mg of brown coal. That factor shows the efforts to reach coal and if considering type of stripping (sand, rock, clay, etc.) it is rough assessment of total magnitude of external loads and stresses applied to excavators. Efforts of machine structure depend mainly on its design, excavating forces, natural conditions and way of operation. All these factors are not precise and not constant over operation process what make difficulties in assessment of safety and machine durability. Huge dimensions and mass cause additional loads due to: mass inertia, stiffness of the structure and clearance in all mechanisms. Aging and wearing processes constantly lower strength of the structure and enlarge clearances. Variable cohesion of excavated ground and coal introduces additional uncertainty to reliability prognosis.

There is a great variety of machines operated in open pit mines. Classification criteria may take into account for instance: functions, design and driving structures, dimensions, efficiency, etc. [1,4]. Main criteria of excavating machines classification are:

- type of excavating tool: bucket wheel, bucket chain,
- type of excavating wheel: bucket, semi bucket, bucket less,
- type of boom: withdrawable, without withdrawable,
- type of undercarriage: rail, caterpillar, walking.

Technology of brown coal exploitation in Poland is based on coal excavation in open pit mines because coal deposits are situated up to 310 m deep under the face of the earth. Excavators, most often bucket wheel and chain excavators, mine for stripping and coal creating terraces. Main movements of the machine are: rotating of wheel boom, lifting and lowering it and running along the cut slope. Principle of excavating process is shown in Figure 3. It is seen bucket wheel and slope with excavating wedges on three levels.

Figure 3. Mining process using bucket wheel excavators [3]

Lay-out of excavator movements, while mining, is also presented schematically in Fig. 4.

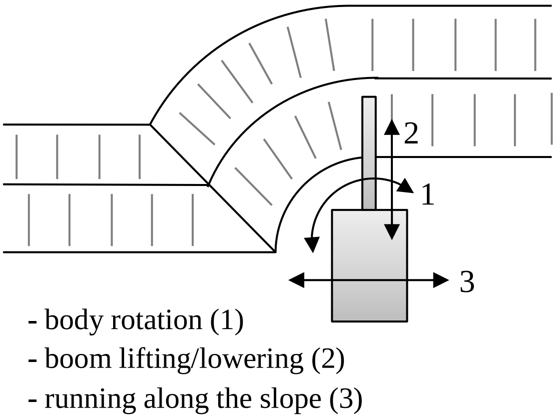

Figure 4. Working motions of bucket wheel excavator

This short description of mining gives an idea of various factors and elements that could be causes of disorder of intended operation process and lead to the catastrophe.

3. OPEN PIT MINES CATASTROPHES OVERVIEW

Operating process of mining machines consists of usage and maintenance processes. Change of state from usage to maintenance may take place due to predefined preventive maintenance or undesired event like mishap, machine component failure or events with disaster consequences called usually catastrophes. It was observed 87 different events classified as minor (59) and major (38) catastrophes. Some of failures repeated more than once and happened even in the same machine. Total number of undesired events has reached 235 and affected 95 machines. Only 23% of all machines were not involved in large breakdown [1].

There are distinguished five main machines’ subsystems discovered as initial cause of the catastrophe (supporting structure, wheel boom, switching funnels, supporting bearings and counterweight lifting system). Only these five units are responsible for number of multiple failures. Main hazards in the excavation process are: overload caused by operator, rocks inclusions, slope slide, fire or technical failure due to ageing or wearing. These hazards are divided in two main groups containing hazards arose from the machine failure, called design imperfection causes and from operation process. Historical data show almost equal part of design and operational causes (Tab. 1) [1].

The most frequent catastrophic events dealt with impact load (120 events) and failure of the system rotating machine body (67 events). More precise analysis shows just for these events the following failure modes:

- impact load:
  - break of the bucket wheel boom structure,
  - deformation of the bucket wheel boom structure,
  - break of the beam supporting bucket wheel gearbox,
  - break of gearbox cogs,
  - crack of the wheel boom structure and superstructure masts,
  - crack of the gearbox and bucket wheel shaft,
- system of the machine body rotating (solid-web girders: lower at undercarriage and upper supporting superstructure):
  - crack of undercarriage supporting portal,
  - crack of welds and structure of solid-web girders.

Table 1: Causes of catastrophes classification

Catastrophe cause	Location	No. of events	Percentage
Design imperfection	Supporting structure	10	49%
	Switching funnel	8	
	Rotating system	7	
	Impact load	12	
	Lifting system	6	
Operational error	Various operational	14	51%
	Spreading process	5	
	Slope instability	18	
	Fire	7	

4. CATASTROPHE EXAMPLES (WRONG READJUSTMENT TO WORKING CONDITION AND UNEXPECTED WORKING CONDITION – SLOPE SLIDE)

The following section shows some examples of large-scale catastrophes resulting in destruction of considerably part of the machine (Fig. 5-9).

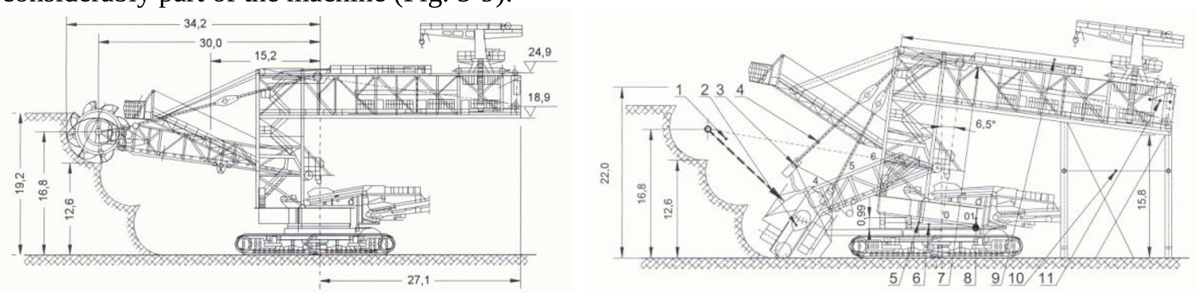

Figure 5. Destruction of SchRs-1200 excavator caused by crack of the wheel boom structure falling-down of wheel excavating boom (drawings before and after catastrophe, picture on-site, dimensions in m) [1]

5. Recommendations as lessons learned

Though machines of open pit mines do not subject to EU Machine Directive, it was introduced recommendations concerning phase of design and operation. It has been formulated safety regulations which order to perform safety analysis and work out field tests of loads and structure strength. It was introduced long-term program of state monitoring, measuring vibrations and data acquisition and processing. New models of degradation and remaining life time was proposed and verified on collected data. Special attention was paid to human error. To avoid errors due to working conditions it was introduced project aiming in building in the machines new ergonomic, vibro-acoustic isolated operator cabins. Catastrophes caused by ageing are no longer observed but still problems of sudden, environmental hazards and, in slighter degree, human errors exist.

6. CONCLUSION

Heavy environmental conditions, unexpected load and high demands due to efficiency of all open pit mine machine introduce in operation management high uncertainty. Undesired events like described above catastrophes lower availability of the output system and rise total output costs. Numerous catastrophes after World War II were caused; despite of operation conditions, mainly from wearing and aging. As a result, couple of excavators was rebuilding according to new regulations and safety requirements. New machines are also equipped with diagnostic systems which allow for data about load and vibration acquisition and processing.

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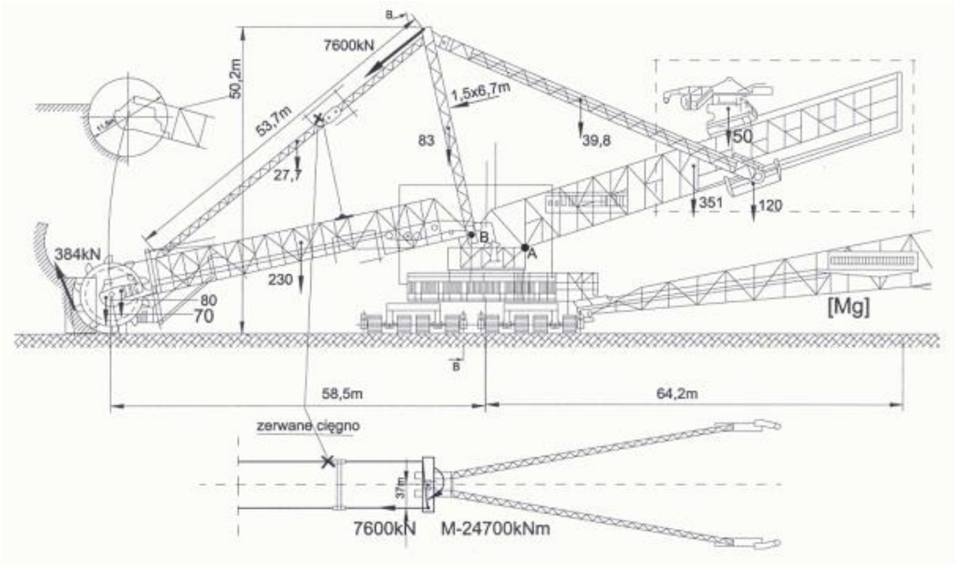

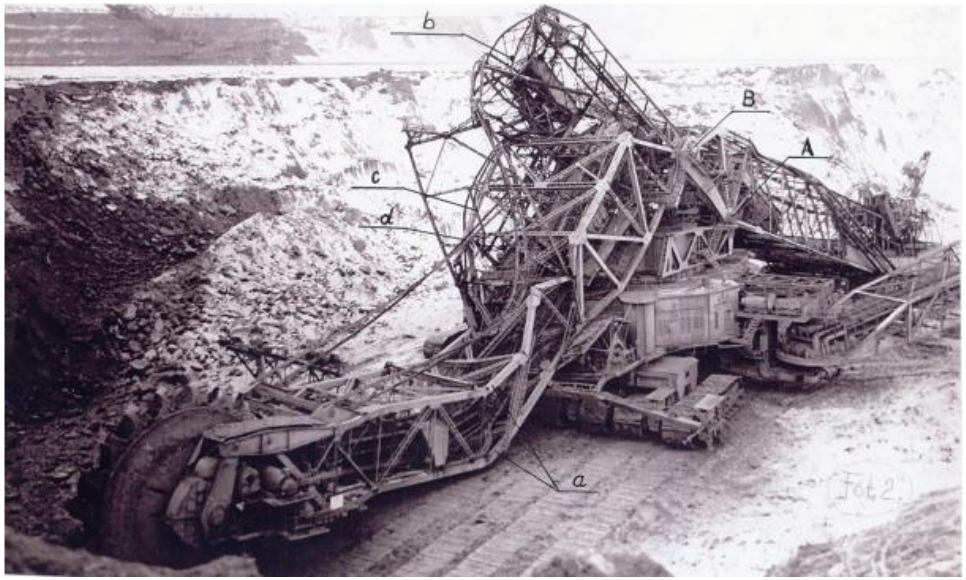

Figure 6. Rapture of one out of two tension members supporting wheel excavating boom of SchRs-1200 [1]

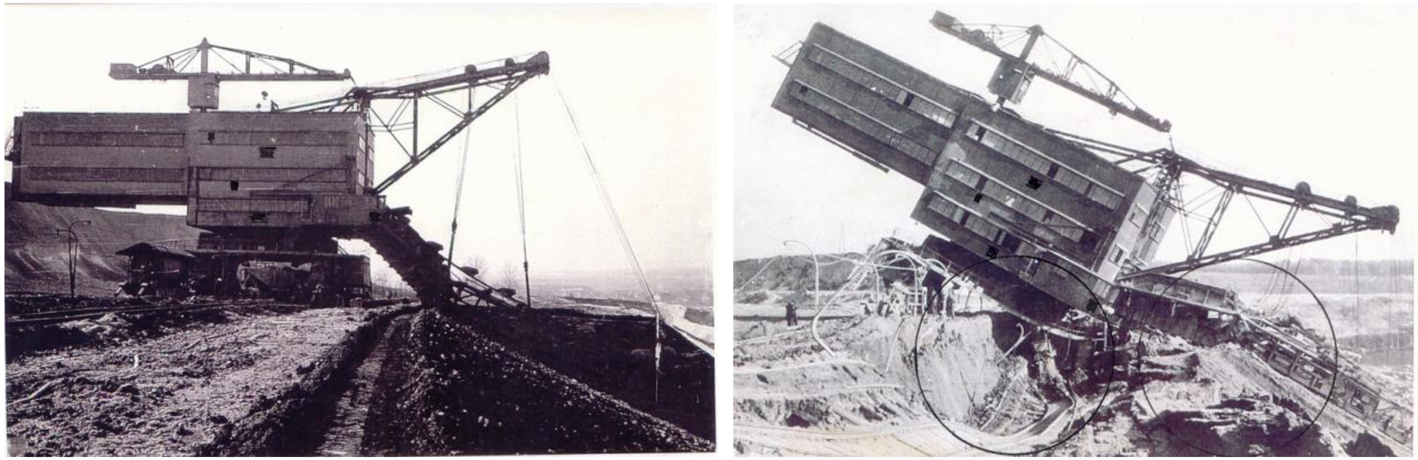

Figure 7. Tilt of chain excavator due to slope sliding [1]

Figure 8. Braking of excavating boom caused by slope creep [1]

Figure 9. Caving of caterpillar vehicle [1]