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Condition monitoring experiences of machines in Hungarian Márkushegy underground mine

This paper presents the results obtained during the years of vibration and current signature monitoring at the Márkushegy mining plant before its final closure. The large amount of recorded data has been used for a statistical analysis that is useful for deriving conclusions regarding the incidence of different kinds of faults occurring at the main underground and surface equipment of an underground coal mine. The importance of an inter-inspection time period on the capability of monitoring to increase up-times is revealed. The gained experience that is disseminated in the paper could be a valuable guideline for designing the condition-based maintenance of operating mines.

Key words: condition-based maintenance, vibration monitoring, current signature inspection, fault prediction

1. FOREWORD

The mining plant in Márkushegy, Hungary's last underground coal mine (which had been continuously producing since 1981) was closed in 2016. At the end of the mining activity, complementary activities also ended, the execution of which supported (sometimes being indispensable) the core activity – coal production.

Such an activity was the running of vibration diagnostic measurements for information on the status-dependent maintenance of the units operating in the mine, in production, and transportation.

At the end of the 1990s, the tools of vibration diagnostics were used in the mine to assess the status of the individual units. The actual paper's aim is to disseminate the accumulated knowledge gained and experienced between 2005 and 2016 as result of this activity.

Initially, only the drive units of the belt conveyors in the surface transport flow were supervised. Over the years, the surveillance was expanded to other equipment; this played the same important role in the good operation of the mine. Over the last few years, the following groups of machines were submitted to vibration monitoring and diagnostics:

- belt conveyor drives, both surface and underground operating units,

- sieves,
- breakers (crushers),
- longwall drum shearer-loaders,
- mine hoists,
- ventilators.

2. MATERIAL AND METHOD

The extent limitations of the paper do not allow for a presentation of the schemes of measuring the set-up for each group of the above listed equipment.

The most important measurement requirements were imposed by the belt conveyor driving unit (electric drives, clutches, gear unit); therefore, we show the measuring set-up layout of this one in Figure 1.

As can be seen, we used several measuring points and directions for the diagnosis of one driving unit. In the case presented in Figure 1, this number is 18 (which is motivated by the extent of the unit and the number of bearings inside).

In Table 1, we summarized the equipment groups listed above with their numbers of units and corresponding numbers of measuring points (directions); this totaled 550.

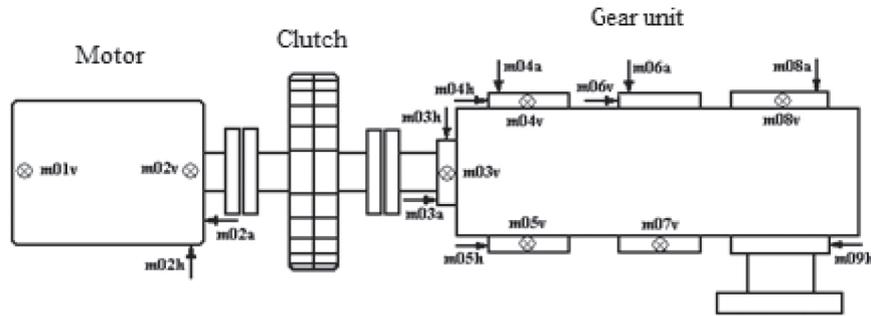


Fig. 1. Measuring set-up layout of belt conveyor driving unit

For each point, at least two spectra were recorded (which means 1100 spectra in all). As the inspection of a unit is performed twice per year (and three times per year for certain units), this accounts for 2200 spectra.

Given the huge number of measurements, the recorded spectra from ten years of monitoring activity represents a strong data warehouse from which valuable information can be gained by using simple statistical tools.

Starting with October 2008, electric current signature diagnosis measurements were performed along with vibration diagnosis measurements. The mine's numerous machines are actuated with three-phase squirrel-cage rotor electric motors.

After a long operating time, damage of the rotor's conductor bars (cage) occurs on these kinds of motors, mainly when they are frequently started under load. As a result, the internal electric resistance of the rotor increases, the characteristic of the motor became weak, and its speed consequently decreases rapidly (even at a reduced load).

This kind of harm is easy to detect by analyzing the motor's current signature. For a detailed description of this issue, see [1] and [2]. This diagnosis monitoring method has been introduced for the critical electric motors as presented in Table 2.

Table 1

Machines examined by vibration diagnosis

| No. | Equipment | Components | Number of examined devices | Number of measuring points |
|-----|--------------------------------------|--|----------------------------|----------------------------|
| 1 | Belt conveyor driving units | Electric motors Gear drives Clutches | 21 | 450 |
| 2 | Sieves | Electric motors Shaft bearings Belt drives | 2 | 24 |
| 3 | Breakers | Electric motors Shaft bearings Belt drives | 2 | 18 |
| 4 | Mine hoists | Electric motors Gear drives Clutches | 1 | 18 |
| 5 | Drum shearer-loaders Ranging arms | Electric motors Drum drive gear chain | 3 | 30 |
| 6 | Ventilators | Electric motors Bearings | 3 | 12 |

Table 2

Electric motors monitored by current signature analysis method

| Equipment | Rated voltage | Rated power | Number |
|----------------------------|---------------|-------------|--------|
| Three-phase electric motor | 1 kV; 6 kV | 160–500 kW | >80 |

The motor's rated power range was 160–500 kW, and its rated voltage was mainly 6 kV (for which the measurements were performed using current measuring transformers). A smaller number of motors were mainly those from the face equipment driving units (at 1 kV voltage and power at the bottom of the range). As they are operating

in a harsh environment, their monitoring was very motivated.

3. RESULTS

In Tables 3 through 8, the description and number of occurrences of the detected damage are presented.

Table 3
Bearing faults

| No. | Equipment | No. | Symptom description |
|-----|--|-----------|---|
| 1 | Mine hoist | 1 | Motor is noisy, vibrations |
| 2 | Inclined shaft driving unit | 1 | High vibration level at the fast stage shaft |
| 3 | Belt conveyor drum bearing | 1 | Dry (not lubricated) run |
| 4 | Belt conveyor drum bearing is tightened | 1 | Diagnosed based on temperature increase |
| 5 | Inclined shaft driving unit fast stage shaft bearing | 1 | High vibration level |
| 6 | Belt conveyor in the 67 roadways | 1 | Shaft is loose in the bearing |
| 7 | Inclined shaft NU324 electric motor bearing | 2 | Detected by vibration signal |
| 8 | Lubrication improvement proposals | 5 | Improper lubrication consequences |
| 9 | Sieve's motor bearing | 1 | Noisy bearing |
| 10 | Breaker bearing housing destroyed | 1 | NOT foreseen by diagnosis because of long inter-inspection time |
| 11 | Breaker bearing housing loose | 1 | Wear of a crushing beam (disc) from breaker (crusher) rotor |
| | Total | 16 | – |

Table 4
Clutch faults

| Equipment | No. | Symptom description |
|--------------------------------|-----------|---|
| Misalignment of coupled shafts | 5 | High vibration level on both sides of the coupling clutch |
| Unbalanced, loose connection | 11 | Usually sealing rings fault |
| Crackling noise | 1 | |
| Total | 17 | – |

Table 5
Gear faults

| Equipment | No. | Symptom description |
|----------------------|----------|---------------------------------------|
| Toothed wheel fault | 6 | Usually bevel gear toothed wheel pair |
| Mine hoist main gear | 1 | Unusual frequency |
| Total | 7 | – |

Table 6
Broken cage bars

| Equipment | No. | Symptom description |
|---------------------------------------|---|--|
| Rotor cage damaged | 12 – From current signature measurement | Broken bars in the cage |
| High vibration; Vibration, rubbing | 3 – From vibration measurement | Many cage bars broken and/or bearing fault |
| Total | 15 | – |

Table 7
Loosening

| Equipment | No. | Symptom description |
|----------------------|----------|-----------------------|
| Sieves | 1 | Loose bearing support |
| Electric motor | 1 | Resonance of support |
| Gear casing loose | 1 | Fasteners fault |
| Motor casing rubbing | 1 | Rotor-stator contact |
| Shaft eccentricity | 1 | Loose |
| Total | 5 | – |

Table 8
Other faults

| Equipment | No. | Symptom description |
|---|----------|---------------------------------|
| Ventilation problem at L3 motor | 1 | Obstruction by dirt |
| Overheating of K1/1 motor | 1 | Brake not released in operation |
| Torque compensator tighten | 1 | – |
| Two driving units' temperature difference | 1 | Thermal imaging |
| Shearer-loader case rubbing | 1 | Cap pressed the bearing |
| Total | 5 | – |

4. CONCLUDING REMARKS

The conclusions to be drawn from the figures presented in the tables are easier to formulate if one calculates the relative frequencies of each group of faults. These frequencies are summarized in Figure 2.

The first notice is that the greatest frequency (~26%) belongs to faults that appear in the bearings. It is no coincidence, therefore, that manufacturers of the vibration monitoring devices afford much weight to develop and manufacture support tools (hardware, software) for early diagnosis of the bearings [3].

The second most common fault detected in the studied set (24.6%) belongs to the misalignment of clutches. Such a fault, of course, has an impact on

the development of the previous group of faults. In fact, the inaccurately set clutches cause overloads on the bearings supporting the coupled shafts [4–6].

Related to the electric motor's diagnosis, it is well-known that the damage of the rotor cage is a common issue. The mechanical vibrations in this case often have a pulsating electromagnetic force as a source, so the use of electrical measurements brings additional information related to the machine's status [4, 5].

The correct choice of control period is extremely important for enhancing the efficiency of the diagnosis. A good example is the fault presented in Row 10 from Table 3 (which was not detected) because the four-month inter-testing period was too long. At this equipment, a reduction in the time between checks would be desirable.

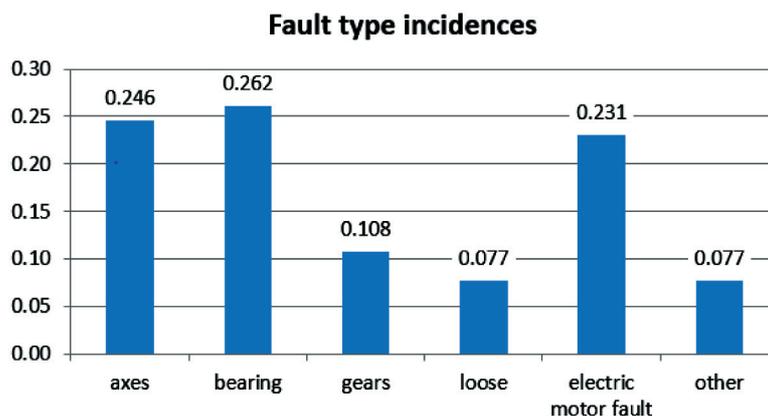


Fig. 2. Relative incidence of faults

We can conclude that the vibration and current signature diagnosis activity performed in the past ten years before the closure of the Márkushegy mine plant contributed to an increase in the availability of the involved equipment and a reduction in the downtimes produced by unexpected faults.

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