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THE HARMONIZATION AND OPTIMIZATION OF DIAGNOSTIC METHODS FOR A BELT CONVEYOR

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Abstract:
The final aim of the project MPO FR-T11/537 called "The Complex Diagnostic System for the Belt Transport" is a single part custom manufacturing and sale of complex diagnostic system for belt transportation and related services. The output of the project is a prototype of a diagnostic system on a model belt conveyor with prepared and certified diagnostic services and methods including their measurements and other supportive tools. The article will introduce the present state of the solution for the given grant project, especially in the field of suggested work on the diagnostic and supportive methods and other measurements.

Key words: *diagnostics, conveyor belts, the prototype*

INTRODUCTION

Basic requirement on machine systems, technologies and machine themselves must be based on a fundamental premise of a safe operation and the maintenance becomes a system tool for system processing activities.

Technological diagnostics thus becomes a deciding maintenance instrument. The technological diagnostics result application means not only a technological hazard minimization but as one production management orthoprocess to fulfil both the maintenance 3P and management 3E principles. Using operational implementation of technological diagnostic methodology represents a basic instrument for the maintenance controlling as a system and for an unwanted fault state elimination which impact production and other aspects influencing a firm activity prosperity.

Technological diagnostics solves the issue of objective determination of a technological state with some showing probability for management by which it becomes a tool for maintenance and production process control i.e. for unwanted technological and controlling factor elimination and man – machine – environment system safety solution and working environment humanization. It is obvious that every future user evaluation will be not only a feed back but a monitoring of the grant project success.

The holistic access builds on a total view on the system, organization or individual and it helps to understand why partial components behave in such way. Faults in systems come:

– as a function of time i.e. aging process in operation,
– as a function of operation conditions i.e. wear, fatigue, etc.,
– as a function of other external influence, i.e. vibrations, dust, emission, radiation etc..

Fundamental principles of design, construction and production must include:

– Occurred technological faults must not cause production process significant hazards. Machinery system must be such constructed so as the fault did not spread even if it is multiple.
– No technological system may accept such information which can create operational danger.
– Each technological system must be adapted to and respect service personnel or operator qualification.
– Operation and maintenance manual must define all possible residual hazards operation endangerments originated from the operation and prevent the operator to give wrong or unqualified command.
– Wear, aging, characteristics decisive for machinery system safe operation must be defined. It is a condition for key machines in production process. These data are needed for assessment of a technological state by prediction or proactive maintenance.
– Diagnosability and reparability design is given mostly in initial stage of the technological life of an object – design and construction and then user ability.

OPERATIONAL RELIABILITY OF BELT CONVEYERS

The conveyers are missed as a potential operation problem in production processes very often but it should be clear the they can be a serious reason of operation break as they mostly cannot be in a reserve in the production process: The premises are given from many year operation experience and decisive factors influencing transportation way reliability and mining process costs include:

- transport belt wear,
- roller life time,
- drum life time.

Operation reliability of transport belts

The transport belt wear means the wear of upper and lower cover layer in operation: The wear is mainly caused by following factors or operation influences

- abrasion with transported material,
- abrasion with material fallen under the conveyer,
- move over rollers,
- abrasion of margins in hoppers,
- slip on drums at starts and stops,
- regular operation on all types of drums,
- increased size and sharp edges of transported material ,
- transport of unwanted objects.

Most frequent damages and faults which can influence the operation reliability of transport belts and are a reason for their early replacement include:

- damaging rubber cover layers or their various wear,
- conveyer belt longitudinal cuts and damaging side rubber edges,
- tear or ungluing of belt joints,
- belt lateral deviation and slippage,
- small and large perforation.

There are some ways to increase operation reliability of transport belts:

- Optimum choice of the construction, type and cover layers of the transport belt. This solution means higher costs for transport belt price but the life time and reliability of the belts is the goal.
- Quality construction and maintenance of the belt conveyers and eliminating all negative influence on the transport belt.
- Introduction of regular revision activities with regular prevention checks of the condition of transport belts and all machine parts which are in contact with the belt during operation.
- Diagnostics of actual state of transport belts and their joints.

Diagnostic methods of transport belt monitoring

SYSTEM OF TRANSPORT BELT AND JOINT RECORD

The system of transport belt and joint record is a base of all diagnostic methodology. The system includes data on transport belt joints and sections in the range that it enables to identify location of damaged point and to record an actual size of the damage and wear rate of the section. Transport belt records include data defined in corresponding standards. Their input quality check should be a part of transport belt record system. Conveyer belt joint records include data of the joint making (belt change, lengthening, shortening, fault, repair, etc.), joining technology, joint label, maker identification, etc. All joints and sections of TB must be uniquely identifiable and a schema of their order with section length is an output of the records.

Used diagnostic methodologies are appropriate to TB purchasing prices and both direct and indirect damages endangering the operator in case of a fault and consequent machinery stoppages. In operation praxis, we speak about:

- VISUAL DIAGNOSTICS AND CHECK.
- STEEL CORD tb SCANNING AND MONITORING.
- RUBBER TEXTILE TB SCANNING AND MONITORING.

Chapters dealing with following issues were written in the transport belt project:

- TB requirements at quarry mining.
- Overview of typical TB damage and wear.

Operation reliability of selected components of belt conveyers

Life time of rollers

The rollers are important parts of a belt conveyer and it is why their life term should concerned because they represent a high cost item. The life time is dependent on a series of factors which overlap and work together:

- Right choice of roller diameter and bearing type.
- Quality of gasket.
- Production and assembly quality and accuracy.
- Roller operation management.
- Use of appropriate (plastic) lubricant.
- Temperature range of roller use.

Decisive technical parameters include:

- Roller life time parameter.
- Untrue run and rotation resistance parameter
- Traffic speed.
- Temperature range of used rollers.
- Tribotechnical parameters of plastic lubricant.

Following methodologies can be recommended for technological diagnostics:

- Thermography.
- Acoustic measurements.
- Reference measurement of newly mounted rollers for their further operation reliability evaluation.
- Contemporary measurement in given operation conditions by both methodologies..
- Disassembly of removed rollers, document them, record their faults and operation interval.

Drum life time

We have not yet mentioned drum and drive construction, lining, etc., as it is designers' unique matter. Drums can influence operation reliability of transport ways and their rolling bearings are key elements deciding the influence on their operation reliability. This imply a need to solve diagnosability of the rolling bearings which will be situated inside the drums in up-to-date constructions. If they are situated outside the drums in bearing houses, a diagnostic measurement is no problem. A classic measurement of drive units determines the diagnosability of conveyer drives.

We do not solve construction of drums even if drum covering and possible slippage can influence transport belt wear as well as the drive unit. Diagnosability of rolling bearings inside the drum remains to be solved only and transport rollers, too. The measurement of driving and all other drums is a main task. And, of course, thermography and acoustic diagnostic must be also used.

METHODOLOGY PROPOSITION OF DIAGNOSTIC, SUPPORTING AND OTHER MEASUREMENTS.

Necessary diagnostic measurements impossible or not required to be carried out on-line or to be incorporated into the belt conveyer controlling system were defined on analysis of the issue, many year experience of solvers and co-solvers, after testing in operating and model conditions in frame of solution of given stage of the grant project. These diagnostic measurements will be included in the et of supplementing diagnostic measurement to which methodologies will be written that can be used and recommended for the monitoring of belt conveyer operation reliability.

Procedures of solving function relations among measured technological and diagnostic parameters were and further will be determined, found out, solved, sometimes verified in the issue analysis and verification procedure on a model conveyer and in situ measurement. Solving function relations between further quantities and technologically simple measurement and economic measurement we get a relevant image of their run.

Module No. 1. Load parametric

Measurement of torsion moment in drive drum shaft

Following ideas must be a part of the measurement and they also imply a task.

- Rotating machine systems have dynamic qualities which decide of their operational vibration responses, i.e. measurement of vibration size at operation is a indirect measurement of dynamic qualities.
- Dynamic analysis is a base to a solution of load condition and resonance problem or a tool of possible construction and operation problems.
- Functional relations between measured vibration size and torsion moment as a load parameter directly in shaft can be expressed mathematically.

TASK No. 1

Found a functional dependence M_{Kvyp} = function (vibration size), compare calculated values to directly measured values (direct tensometrically in the shaft - M_{Ktenz}) and indirectly (calculation from drive power - MKpřík) and the determine $M_{Kpřík} = f(Q_{SKUT})$ and $M_{Kvyp} = f(Q_{SKUT})$, i.e. dependence on transported mass on belt conveyer (conveyer weights)

Measurement of drive unit power

Verification of the procedure is based on an in situ measurement. The measurement was carried out at start-up of the conveyer without and with material, at idle run and with material, and at stop-down of an empty conveyer and with material, in both automatic and de-block modes. Further quantities of the conveyer drive were measured too:

- drive power,
- tensioning force,
- drive drum shaft rotations,
- material mass on the belt,
- drive unit vibrations.

Use of these measurements will be described below. *Proposal of contents of methodology of measuring power on belt conveyer drive drum* will be an output of belt conveyer drive power measurement.

Module No. 2. Diagnostic

Measurement of drive unit vibrations

The measurement can be used for evaluation of belt conveyer drive states measured with usual devices for vibration diagnostics which enable measurement oscillation velocity v ($mm.s^{-1}$), RMS or peak value.

Determining and choice, mark-up, preparation of measuring points and definition of conditions and time interval of measurement are concerned with in the first and this implies following task.

TASK No. 2

Work up a procedure proposal of a term calculation of next measurement of vibro-diagnostic qualities of observed subject. The procedure will proceed from carried-out measurements and from estimation of point or interval remaining life time. The probability of life time end cannot step over a value given with faultless conditions in the interval till following measurement.

Calculation of fault (operation) frequencies in spectre, classification of machine vibration massiveness according to ČSN ISO 10816-3:1999 and so a formulation of next task followed.

TASK No. 3

Mathematic statistical verification of vibration massiveness classification according to given standard for operation characteristics and to determine new vibration limit values from measurements carried out on the given object. The procedure must usable for verification of any existing classification of vibration massiveness.

The *measurement itself and evaluation of measured data – diagnostic interpretation* is a logical continuation. Prediction of prognosis of remaining life time or determining time to reparation and formulation of these tasks is the goal.

TASK No. 4

Elaborate mathematic statistical calculation of remaining life time from measured vibration values i.e. estimation of mathematic statistical characteristics of a random time dependence of vibration velocity of observed object. Propose relation for calculation of point and interval remaining life time outside estimation of regression function coefficients and residuum dispersion. Solve an issue of distant measurement exclusion.

TASK No. 5

Procedure given in task No. 3 would not be possible to use in start of the measurement or at insufficient measured set and it is why a modelling of time run of a vibration quantity must be used. Results of existing measurements will be the starting point to which results modelled by Monte Carlo method are added in various time intervals. Every model is finished by reaching a final value by which a distribution of residual remaining life time of every object can be determined.

As the procedure was verified with operational measurement, a *proposal of the content of methodology o measurement of belt conveyer drive unit measurement* is an output here.

Tribotechnical measurements of gearboxes of drive units

Information of lubricant quality and degradation and information of technical state of the object will be obtained from tribodiagnostics or tribodiagnostic measurements. Friction increase is among first symptoms of every damage in rotating object which means wear increase and products of wear enter lubricant. *Taking a representative oil sample* is the first step *followed by evaluation of tribotechnic measurements*. As another diagnostic quality is acquired by the measurement The task can be formulated.

TASK No. 6

Elaborate a mathematical procedure of prediction of prognosis of remaining life time of diagnosed object using two diagnosing quantities. Respect two possible procedures in calculation. The first is based from the time run of partial results of both diagnostic quantities and the second from individually calculated remaining life time in each of used diagnostic methodologies.

As the procedure is verified there is an other output in belt conveyer drive application in form of a *proposal of methodology contents of tribodiagnostic test of gearboxes of belt conveyers drive units.*

Drum vibration measurement with microsystem

Frequent bearing faults in returning and dust drums which mean unplanned stoppages of all production lines can be often met in operation praxis of brown coal open pit mines. Operational state monitoring of the drum bearings is made with acoustic measurements or determining drum face temperature. Monitoring technological state of bearings and their further development can be more precise by measurement of frequency characteristics drum vibrations. It comes to question which system to use.

The drum vibration must be measured on-line, not off-line. The off-line variant can be solved by measuring on bearing case or on a steel construction where are the drums situated. Hence a device was developed which can be incorporated in drum construction and which will continuously measure vibration characteristics, observe their development in time and forecast possible bearing faults. Vibration spectra of belt transport drums are measured in non-standard way using high frequency vibrations at defect creation. Drum bearings are equipped with independent vibration sensors with their independent electronics manufactured with microelectro-mechanic system technology which combines all needed accelerometer and necessary electronics into a system with miniature dimension and relatively low cost.

Theromgraphic measurement of transport rollers, transport belts and bearings inside drums

Thermovision system cam measure and display infrared light radiated by an object. The radiation is a function of temperature and it enables the camera to calculate and display the temperature. Radiation measured by the thermovision camera is dependent on ambient environment but it is a function of emissivity. Radiation is also generated n the ambient surroundings of the measured object and it is reflected by it. Radiation of object and reflected radiation are influenced by absorption at the atmosphere. To measure (calculate) the object surface temperature exactly a compensation is needed for various effects of radiation sources. This is made automatically in camera but further parameters of object must be input (set). They are emissivity, ambient temperature, distance from measured object, relative humidity, initial thermal condition of rotating parts of belt conveyer, and condition of operation temperature measurement.

Thermovision measurement is carried out to determine:

- surface temperature of rollers and drums,
- spatial distribution of the temperature on roller and drum surface,
- percentage representation of temperature in selected areas in surface of measured parts of belt conveyers,
- thermal stress of the object.

As a series of verifying operational measurements was done, a *methodology content proposal of thermovision measurement of traffic rollers, traffic belts and bearings inside drums* was elaborated.

Wear measurement of traffic belts

This chapter procession is in complete accord with analysis made in chapter 1.2 Operation reliability of transport belts. The output is defining the contents of appropriate methodology i,e. *methodology content proposal of thermographic measurement of transport belt wear*.

Principles of belt conveyer life time tests

Summarising facts mentioned above and generally known we can state that principles for testing life time of belt conveyers should be following:

- Investment to machine in a production process is better used after right evaluation of information from information analysis.
- Reputation of reliable producer and supplier is given and stays on operation ability and operation reliability.
- Reliable device for competitive price is a way of development and keeping on market.
- Continuous improvement s a steady principle of all management systems.
- Maintenance control is a part of production control.
- Only predictive or proactive maintenance can secure a reliable operation and maintenance can be controlled as a tool for operation reliability.
- Every user requires and expects high operation reliability and operability of production device.
- Operation reliability determines maintenance strategy.
- Production process without unpleasant surprises of faults and breakdowns is a dream of every producer.
- Maintenance is a mean to manage, decrease and control hazards and operation safety.

It is obvious that life time tests support up-to-date trends in maintenance control and management. Maintenance represents process of all technological and administrative activities during object all life cycle aiming to create such state in which the object can do required function at optimum costs, fulfilled quality, safety and environment requirements.

Design construction and production of the model conveyer were carried out with following goals:

- enable short and long time measurement and measuring procedure verification, a traffic cycle of two conveyers was created,
- enable tests of life time and operation reliability of belt conveyer basic components,
- enable tracing and dividing operation and diagnostic parameters to online (controlling system) and off-line (cyclic or ordered measurements),
- enable such measurements which cannot be carried out in a real operation from objective or subjective reasons.

Acoustic diagnostics of transport rollers

SKF Idler Sound Monitor set comes to market thee days. The set uses an envelope procession technology applied to a sound signal and it discriminates between sounds of a good roller and a roller with fault. The set is said to enable an earlier fault detection than a thermovsion camera use. An easy understandable visual alarm as traffic lights is displayed on SKF Micrhim screen in the Idler Sound Monitor module. An other task can be defined

TASK No. 7

If made possible, to carry out comparing common measurement with the SKF company on the same rollers and in same time, or to verify a constatation of a priority of the diagnostic signal from the SKF Idler Sound Monitor set in comparison with thermovision.

Module No. 3. Parametric

Belt conveyer productivity and transported material lump rate

A classic procedure is used in a routine operation i.e. determination of productivity by means of belt weights built in to belt conveyer, and comparison of their values to those of geodetic measurements n a mined block .

Fragmentation of transported material is carried out on base of snaps taken on the belt conveyer. All pieces with edge longer than 400 mm are evaluated. the pieces are sorted to intervals of 100 mm. Total number of pieces over 400 mm edge length per 100 m belt length is taken as a base for percentage expression of pieces number in single interval.

Laboratory analysis of transported matter

It is determination of physical qualities and a chemical petrographical test, determination of compression strength in Testing accredited laboratory No. 1078 at VUHU, j. s. c., in Most according to ČSN EN ISO/IEC 17025. A certified protocol is issued for the analysis. Sample taking of transported material is the only needed activity.

Module No. 4 Load.

Tensile forces in branches of transport belt and its tensioning force

Determination of tensile forces in a transport belt bases on drive parameters and on usual calculating procedures of tensioning forces at a two drum drive [2, 3, 4, 6].

TENSIONING FORCE

It was read with a tensometric sensor connected to drive station control system.

ROTATIONS OF DRIVE DRUM SHAFT

They were read with an incremental sensor connected to drive station control system.

Measured values and values of drive power were used to an indirect determination of circumferential force on the drive drum and tensile forces in the transport belt. Parameters from [1] were also necessary to be known for it. Complexity of tensile force determination can be easily seen from above and it means an other task can be formulated.

TASK No. 8

Determine function dependence of the belt tensioning force as a function of the conveyer drive twisting moment i.e. F_{nap} = f ($M_{Kpřík}$ and M_{Kvyp}), or tension in the belt as a function of power T = f ($P_ř$).

A proposal of methodology content of the determination of tensile forces in a transport belt was elaborated during the grant project solution.

Determination of operation qualities of rubber transport belts by means of mechanic dynamic measurements

Detailed knowledge of physical qualities of rubber cover layers of transport belt has a fundamental signification or determination operation and use quality of transport belts. Cover layer qualities are adjusted to operation conditions and they are produced in more than ten types fro various transported material and operation conditions and according to standards. The standards determine required quantities of rubber cover layers at room temperature (ČSN 26 0381), but transport belts are regularly used at wider temperature range given by climate conditions, belt warm up caused by operation or transported material. The standards do not determine requirements for characteristics at temperatures lower or higher than in laboratory. But mechanical qualities of rubber which play a significant role at their use in transportation are heavily temperature dependent

Many physical qualities change with temperature changes at polymers and polymer nets to which rubber used in belt transport belongs. Transition from glassy state, so called glassy transition, is characteristic for them. Rubber is in glassy state characterised with high mechanic module (order 1000 MPa) under glassy transition temperature. The module decreases with temperature increase in glassy transition range. Rubber is in gum elastic state at temperatures some ten degrees higher than vitrification temperature ant it can be used for transport belts. Module is reached at room temperature in new belts when the above condition is fulfilled (10 to 20 MPa [5]).

Rubber layer looses its elasticity and strength if elasticity module is higher than optimum value. It can mean its destruction – chapping. The module can increase with temperature decrease to glassy transition range. If the rubber elasticity module is lower than operation values cover layer of transport belt can be abraded more which is not desired. Thus the module value determines whether the belt will be possible to use at given temperatures.

Physical qualities of rubber cover layers change during belt conveyer operation. The changes are called ageing. Rubber cover layers age due to meteorological conditions e.g. temperature change, long term warm up by mechanic looses during operation, ultraviolet radiation, air oxygen. Transported material also takes its part on quality change. Upper cover layer of transport belt is influenced most as it is in contact with transported material and a surrounding ambient. Quality changes of lower cover layer are less significant in comparison with upper cover layer changes.

Changes of mechanic properties of used rubber as net density, glassy transition temperature elasticity module value, hardness, tensile strength and ductility are significant in belt transport operation and they will be dealt with in this chapter. We deal with measurement of dynamic mechanic qualities of rubber cover layers in dependence on temperature with a goal to determine operational qualities of transport belt rubber in a wide temperature range. More in [1] and [5]. As many laboratory verification tests were carried out the output is *methodology content proposal of observing transport belt rubber cover layer qualities*.

CONCLUSION

Current European legislation mainly on machine operation safety emphasizes safety level increase of devices realising the base in design and construction of devices. it is necessary to create measuring points to observe technical state of the machine with methods of technological diagnostics e. secure diagnosability which will create condition for fault prevention and definition of an objective technological state in operational conditions. According to the European directive, a relevant solution must unconditionally occur in service manual, i.e. activity description at setting and maintenance by operator, instructions which enables to carry out safely activity at setting and maintenance, including health and safety prevention precautions, etc.

European legislation is mirrored in the ČSN EN 13460: 2009 standard edition in which it is introduced: „Maintenance as every other function in business activity needs an information flow among various points of the internal organisation and other functional and organisational business units to reach goals and acceptable values of maintenance productivity indices". General directives for technical documentation are determined in the standard. The documentation must be supplied before starting operation. Another documentation must be supplied in operation stage to meet maintenance requirements. Short selection from its stages follows:

- Preparation stage documents – maintenance manual (searching and remedying defects, reason and consequence diagrams, required tools, etc), lubrication plan (working procedure, etc.), test programme report (other physical quantities, etc.), etc.
- Operation stage documents - reason and consequence diagrams, (according to importance order and consequence), parameter chronologic record (for a specific period), MTBF-MTTR regulation diagram (statistic information at key objects), object use and readiness record sheet (use and lock), maintenance activity control procedures (maintenance records), object monitoring and testing procedures during inoperable state and during operation, and others.
- Information stated in work order (maintenance period, fault reason etc).

And here we can see one of the basic questions „What are these documents filled in with from today's point of view". This grant project should give an answer to this question for belt conveyers, or diagnosability assurance through proposed measuring methodologies and technological equipment of belt conveyers.

An assistance system will be created by joining technological diagnostic methods and controlling system. Assistance systems for a decision process gives a needed support which is above standard n application to a specific task corresponding to object and process functionality in comparison to classical products:

- support of a user to effective decision based on his high certainty,
- integration to working and production process of user,
- they are tailor-made for given user object or process,
- content relevant information for a user,
- they give a decision alternative to user.

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