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CASE STUDIES OF AUTOMATED ROPE CONDITION MONITORING SYSTEMS

Summery

The concept of automated condition monitoring of steel wire ropes instead of conventional non-destructive testing resonates with industrial companies but rarely comes to the practical implementation of these systems due to a number of challenges of both technical and organizational nature. In this context, a detailed presentation of experience in the implementation of the Intros-Auto automated condition monitoring system (ACMS) for wire ropes at mining and drilling facilities. This could be of interest for other companies. In contrast to conventional rope testing instruments, the ACMS can be customized for each individual site, integrated with other measuring equipment of the hoisting machine, and provides commonly used criteria for rope condition and discard. Integration of rope condition monitoring into site's information system is particular important, so far it provides essential information for asset management and planning operations. Another important point is the reliability of the reported rope condition data. It depends on several factors: probability of wire break detection, probability of false-signal detection, accuracy of LMA estimation. Particularly important is the accuracy for estimating the number of broken wires in a cluster.

1. Introduction

Conventional magnetic rope testing (MRT) has proved itself as an efficient and reliable technique of steel wire rope non-destructive evaluation. It enables one to locate and numerically estimate loss of metallic cross-section area (LMA), caused by corrosion or abrasion, and to detect internal and external wire breaks [1]. Common MRT inspection involves setting up equipment, carrying out of the test procedure, evaluation of recorded inspection data — typically LMA and LF (local fault) signals. There are two main limitations of this approach. Firstly, it cannot be done regularly enough to detect rapidly developing defects that can appear during intensive lifting operations, for example in offshore or drilling. Secondly, it requires engagement of qualified personnel to interpret inspection results correctly. Automated rope condition monitoring offers a good alternative to conventional MRT, while giving a possibility to be applied daily and with immediate availability of test results. However, a monitoring system should be customized for the specific industrial installation and tuned at the rope to be monitored. To achieve best results monitoring system should be integrated into the rope user's information system. This paper provides several examples to address this topic.

General concept of rope monitoring system

Instruments designed for rope conditional monitoring should have some special features, which distinguish them from common rope testing instruments. Monitoring systems should have a rugged design and be robust against different influence factors such as environmental, mechanical or operational. At the same time, it should be very easy to operate and ensure high reliability of inspection results. Sensors should have high sensitivity for defects (wire breaks) and low levels of adverse influence factors. The system should perform automatic data interpretation; results should be unambiguous and comprehensible [2]. At the same time, it should allow verification of these results. This means that results should be stored over a considerable time and be available for external review.

Intros-Auto rope monitoring system

The Intros-Auto rope monitoring system consists of a magnetic head (MH) and a control and display unit (CDU) connected by a cable. CDU also has auxiliary connectors for the external odometer and a rope-tension meter. Depending on the application, MH is to be permanently installed on the rope pathway (Fig.1), as for mine hoists, or stored proximately to the rope to be quickly put on the rope for inspection procedure. The CDU is typically mounted in the control room of the hoist operator (Fig.2). Measuring the performance of the monitoring system conforms to the requirements of international standards for MRT, in particular to ISO4309 [3], measuring accuracy for LMA amounts 2%, sensitivity to wire breaks is equivalent to 0.5% of metallic cross-section. So in particular for 6-strand rope (6x19S-IWRC) of drilling rig a caution (amber) threshold is set as 8 % of LMA and 6 wire breaks at 6D length, 8 wire breaks at 30D length. Alert threshold (red) is set as 10 % of LMA and 8 wire breaks at 6D length, 12 wire breaks at 30D length. According to ISO 4309 for this rope for the case of MRT discard criteria of 6D would be 9 wire breaks.

To increase reliability of wire break detection, two different LF-channels are applied: one sensor performs better sensitivity to outer wire breaks and another – better sensitivity to internal wire breaks. One of the essential features of this system is that preparation for rope inspection and inspection itself takes minimal time and puts no special demands on staff qualifications. Information about inspection results is available immediately after finishing the rope run through: depending on detected defects and in accordance with discard criteria, green, yellow or red LED goes on, detailed information can be read on the display.

Figure 1: Magnetic head of Intros-Auto at the 56-mm rope of the mine hoist.

Figure 2: Control and display unit of Intros-Auto in the hoist operator booth

2. Implementation of monitoring system for the ropes of drilling rigs

Since 2014, INTRON PLUS has implemented its rope monitoring system at more than 20 drilling rigs of different oil and gas service companies. A distinct feature of this realization is that MH is rather compact and is not fixed constantly, but should be mounted for every testing procedure, so it can be applied in the case of extensive transverse movement of the rope, typically above the line spooler of a winch (Fig. 3). Rope testing is to be performed before every shaft, normally twice a day. The result of the inspection appears on the display of CDU located in a booth of the drill tower operator. The rope-tension meter and external odometer can be connected to the CDU to realize tonne-millage counting additionally. An operator switches the system on and off and sees results on the display. Inspection results can also be immediately remotely checked by a rig supervisor. It is important that every time the same part of the rope is being checked, this makes it possible to compare successive inspections with each other to find out a moment as a rope begins to deteriorate intensively. The rate of defects growth is used as an additional gauge of rope technical condition.

Figure 3: MH of Intros-Auto at the 28-mm rope of the drilling rig

For the verification of Intros-Auto performance, the section of discarded rope marked by the system as critical (red LED indication) was cut out and disassembled to count the number of broken wires [4]. So at Fig. 4 a short un-stranded part of 28 mm rope is shown, the number of proved broken wires at 6D length was 27. Set in the system discard criteria was 21 wire brakes at 6D (the system estimated the number of wire breaks as 23), therefore the rope was discarded correctly. Previous testing had been carried out a day before and it had shown only a yellow indication. This procedure was repeated twice in 2016 at one of the drilling rigs and it confirmed proper operation of the monitoring system.

Figure 4: Disassembled section of the automatically discarded rope

The main factors that affect the operation life of drilling rigs hoist ropes are as follows:

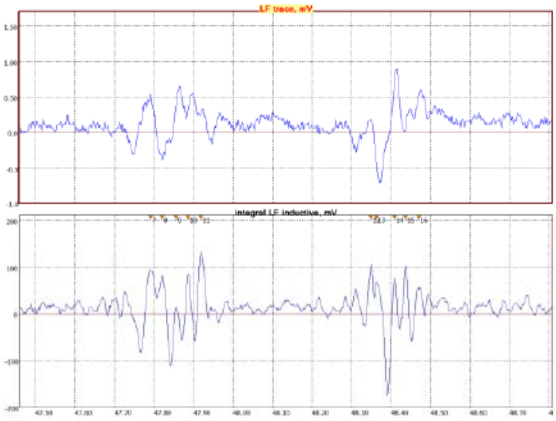
- Cyclic tension stress, sustained by rope wires;
- Cyclic sign-changing bending stress of rope wires during its passing through the hoist sheave, crown block or on the winding drum;

- Oscillatory movement of the rope during its operation, which leads to significant dynamic load;
- Abrasion of external wires because of friction at a pulley.

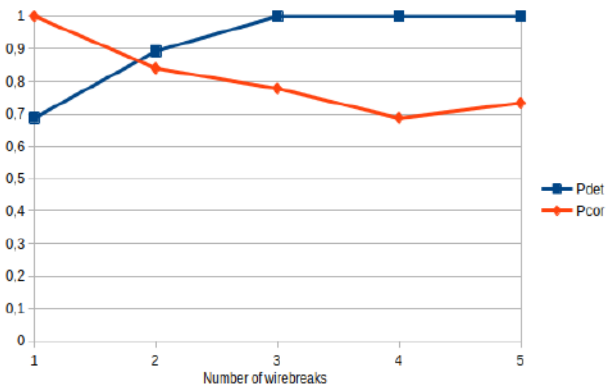
The effect of these factors defines a typical defect type of hoist rope — distinct wire breaks and clusters of wire breaks. Clusters of wire breaks are especially dangerous because they indicate fatigue damage of the rope. Detection and numerical estimation of wire break clusters plays a crucial role in the reliability of rope monitoring.

3. Defect detection characteristic (POD) of Intros-Auto rope monitoring system

Since detection of wire breaks plays such an important rope in rope monitoring, a probability of defect detection (i.e. detection of single wire breaks) and a probability of correct estimation of wire breaks number in a cluster becomes an important characteristic of the system. Figure 5(a) shows signals of two different LF-channels (from an inductive sensor and from Hall sensors) from a cluster of wire breaks. The first channel allows increasing detection probability whereas the second enables proper estimation of number of wire breaks. Several dozen of LF traces throughout the lifetime of two different hoist ropes were analyzed to build probability characteristic. It is shown at Figure 5(b).



a



b

Figure 5: (a) – LF signals at the clusters of wire breaks, (b) – POD curve for Intros-Auto

A blue curve (Pdet) represents the probability of detection (POD) depending on the percentage of broken wires at a given location, while a red curve (Pcor) indicates the probability of correctly estimating the absolute number of broken wires. As expected, the POD increases with the percentage of broken wires in a cluster. Meanwhile, the probability of correct number estimation decreases slightly but not significantly. Overall, the Intros-Auto system has a probability of detection and correct quantitative estimation for local defects that exceeds 70%.

4. Implementation of monitoring system for the ropes of mine winder

Besides drilling rigs, the rope monitoring system is especially relevant at mine winders. Mine ropes deteriorate in some other way than drilling rig ropes. In particular, head ropes are exposed to the most severe operation conditions. There wires have to withstand cyclic tension-bending loading, friction forces, the action of a hostile environment. These influence factors cause such kinds of rope deterioration as abrasion of both external and internal wires, corrosion, wire breaks. Over time, individual wire breaks develop into clusters.

Considering specificity of mine winders elements of the rope monitoring system should have another design than such for drilling rigs. An important specific feature is a stationary installation of MH on the rope, which means a big air gap between a sensor and the rope under the test (see Fig.1). It sets special requirements for a magnetic and measuring system of MH: 1. LMA measurement should be not susceptible to rope displacement in MH, 2. LF sensitivity should be optimized for an actual air gap. Additionally, it should be considered that condition evaluation of mine ropes assumes higher accuracy of LMA measurement – typically 1 %, which is necessary for the estimation of deterioration, caused by corrosion and abrasion of the rope. A special automatic calibration procedure enables reduction of measurement error. Furthermore, the rope monitoring system for mine winders provides more extensive functionality than the system for drilling rigs because of the requirement to integrate it with the information system of the mine. In particular, distance indication in diagnostic information should be synchronized with data from the hoist odometer; besides that, testing can be done simultaneously at 2 or 4 ropes of mine winder.

Over 30 rope monitoring systems for mine hoists have been implemented since 2020.

5. Integration of rope monitoring system with an information system of industrial facility

While implementing monitoring system at different industrial facilities, it is important that actual information about the rope's technical condition reaches the designated person in a timely way and in proper presentation. It provides for correct technical decisions and planning of rig/winch maintenance. This means that monitoring system should be integrated into the general information structure of the enterprise. There are several aspects which can be elaborated.

Firstly, the rope monitoring system should enable remote control for all installed units from one operator's desk. Its operation should be synchronized with the operation of the winch or hoist. Secondly, the rope testing data (in the form of measurement signals) should be stored over a considerable time for possible detailed analysis also by external experts if necessary.

Thirdly, results of the rope monitoring can be sent automatically as electronic messages to service staff and to the rig or mine supervisor, so that it provides an opportunity to plan in advance necessary rope service operations or engage external experts to analyze diagnostic data. In this context, a form of data presentation plays an apparent role. For example, Fig. 6 shows an incremental report, which can be automatically generated for serial testing of the same rope for some time span (yellow background of the last line corresponds to yellow indication at CDU after rope testing). It was made on the basis of successive rope testing at one of the drilling rigs, where the Intros-Auto system was installed.

Report about technical condition of the rope based on its monitoring by INTROS-AUTO

Monitored item: Drilling rig, "Enterprise N"
Rope construction: GOST 16853-88 O.C.
Rope diameter: 25 mm.

Date and time of rope testing	Length of inspected rope part, m	Detected defects			Dynamics, increase of wire breaks number to the previous testing	Condition (technical condition of the hoist rope)
		LF (over whole length)	Maximal LF density (over 6d)	LMA, %		
1	2	3	4	5	6	7
31.03.2020 21:10	51	0.0	0	0	0.0	Usable condition
01.04.2020 11:19	62	0.0	0	0	0.0	Usable condition
01.04.2020 21:16	65	0.0	0	1	0.0	Usable condition
02.04.2020 11:28	63	0.0	0	0	0.0	Usable condition
02.04.2020 21:03	65	0.0	0	1	0.0	Usable condition
04.04.2020 14:49	70	0.0	0	0	0.0	Usable condition
04.04.2020 21:24	60	0.0	0	0	0.0	Usable condition
05.04.2020 09:55	77	0.0	0	0	0.0	Usable condition
05.04.2020 09:56	111	0.0	0	0	0.0	Usable condition
06.04.2020 09:04	75	0.0	0	0	0.0	Usable condition
06.04.2020 09:05	40	44.0	12	0	44.0	Limited usable condition

Figure 6: An incremental report of rope testing over selected time period

Conclusion

For successful implementation, the rope monitoring system should be optimized for a specific industrial object. The monitoring system should ensure detection of typical rope defects with a reliability similar to that achieved with conventional MRT. Accuracy of rope deterioration estimation should also agree with that for MRT, so that general discard criteria can be applied. Results of rope monitoring should be streamed in a timely way into the information system of the enterprise, and the monitoring system itself should enable its remote control.

Reference

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Author introduction

Dr. Dmitry Slesarev received his PhD degree in physical measurement techniques from Moscow Power Engineering Institute (Technical University) in 1996, received Dr.-habil. degree in non-destructive testing techniques in 2017. He started his professional career as a research fellow at NDT department of Moscow Power Engineering Institute in 1990, since 2003 he works at R&D department of “INTRON PLUS” company. His research interests are in development of data processing technique for electromagnetic inspection

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