VISION METHODS FOR ASSESSING THE GEOMETRICAL PARAMETERS OF STEEL ROPES

Andrzej SIOMA[*], Andrzej TYTKO[**]

[*] AGH University of Science and Technology, Faculty of Mechanical Engineering and Robotics, Department of Process Control, Al. A. Mickiewicza 30, 30-059 Kraków, Poland
[**] AGH University of Science and Technology, Faculty of Mechanical Engineering and Robotics, Department of Rope Transport, Al. A. Mickiewicza 30, 30-059 Kraków, Poland

andrzej.sioma@agh.edu.pl, tytko@agh.edu.pl

Abstract: This article discusses a vision method of measuring the geometric parameters of ropes and evaluating their wear based on measurements made in a three-dimensional rope image. The article discusses the method of construction of a three-dimensional image based on mapping of the actual dimensions of the rope and on algorithms that allow determination of the parameters describing its basic geometrical dimensions and surface condition. The article discusses issues related to resolution of the vision system, resolution of laser beam analysis, and resolution relating to the measurement of the height profile on the surface of the rope. Based on the image constructed in such a way, measurements are presented in order to assess the dimensional parameters and surface defects in sample rope structures. Based on tests and analyses of the three-dimensional image, a range of inspection tasks using 3D vision systems is indicated.

Key words: 3D Vision System, Rope Defects, Rope Diagnostics, Rope Model Resolution

1. INTRODUCTION

Steel wire ropes are the fundamental element crucial to the safety of operation of all devices in which they are used. They include a very broad range of machines: cable railways, mine shaft hoists, passenger and cargo lifts, cranes, gantry cranes, winches, off-shore equipment, and many more. Steel wire ropes are popular because their wear characteristics and methods of determining service life are well-known (Tytko and Sioma, 2011). All ropes used as intended are taken out of service In accordance with one of three principles: service life to replacement results from an arbitrarily adopted value, service life to replacement is determined by the amount of work done by the rope, or (most commonly) numerical criteria for discarding as a result of identified actual level of wear or degree of weakening are provided for in relevant regulations (Kowalski et al., 2009).

In most countries, supervision of the safety of operation of ropes and the associated equipment is mandatory and is stipulated by law. The rule of three parties is applied. The user is legally responsible for the operational safety a rope device and is obliged to prove that the condition of the device, including the rope, is good, i.e. fulfils the requirements of relevant regulations. Ropes are tested with non-destructive methods by certified staff, usually external companies. In the case of ropes, two main methods, which are prevalent in various ways, are used: magnetic rope testing (MRT) and visual testing (VT). The third party has inherent legal competence to permit further use of the device based on evidence in the form of certificates or expert opinions on the condition of the device. Procedures, measurement methods, certification of NDT staff, and criteria for discarding ropes are usually regulated by local laws, but also, for example, in the case of cable railways in European Union countries, by laws or regulations at national level and by normative acts.

For the last several years, users of rope transport devices and ropes researchers have been witnessing constantly improving quality of ropes, especially in new structures. Therefore, the existing measuring methods for assessment of the degree of wear applicable to many applications of ropes are not sufficient any more. An example might be the visual testing method, which, in addition to visual inspection, measures the basic geometric parameters of the rope, i.e. diameter and length of the pitch. Those parameters or, more specifically, changes thereof with respect to the standard values determined during routine testing of ropes can be the basis for assessing the degree of wear. Fig. 1 shows an example of correct and incorrect measurement of rope diameter using that method (Tytko, 2003; Tytko and Sioma, 2011). Measurement of rope diameter using the presented method has also other limitations. It is inherently random and feasible in very few places (cross-sections of the rope). Even more difficult and less precise is measurement of the pitch length of a working rope.

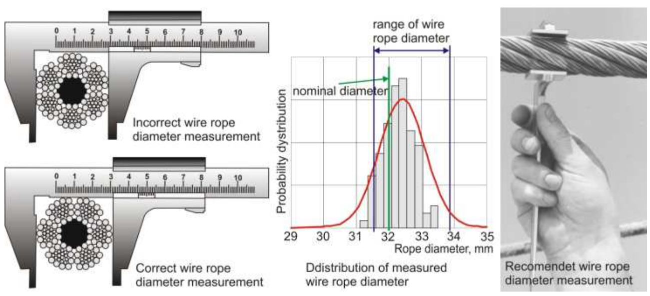

Fig. 1. Correct and incorrect method of rope diameter measurement

Typically, a measuring tape is used. There are also methods of determining pitch length on the basis of signal frequency analysis in magnetic rope testing (MRT), but such methods do not allow simultaneous instrument-aided measurement of the diameter

(Kowalski et al., 2009; Tytko, 2003). To date, there has not been a good and simple measuring method which would enable continuous and simultaneous measurement of stroke length and diameter of the rope. A method of continuous measurement of those two parameters that is simple to interpret, in addition to diagnostic applications, is of great operational significance. Both parameters significantly affect the durability and service life of ropes and associated components. This is illustrated in Fig. 2, which shows the effect of changing the diameter of the rope on its fatigue life in the context of dimensions of the collaborating rollers and pulleys. Monitoring of rope diameter would allow rational use of ropes working in pulley systems.

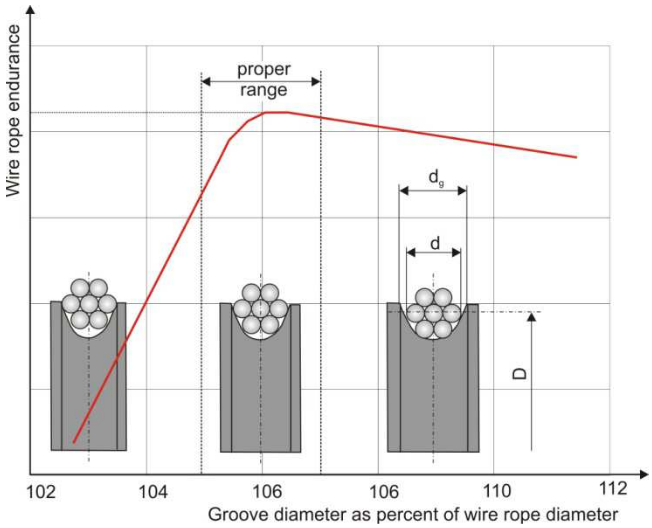

Fig. 2. The effect of rope diameter on its fatigue life

As outlined above, there is a reasonable need to supplement the non-destructive testing methods with new ones, allowing continuous measurement of the diameter and pitch length. Among the many possible concepts, methods based on spatial visualization (model construction) of the rope seem to be most promising. Below, such a method and its advantages are presented. From the viewpoint of diagnosing steel wire ropes, it is a totally new concept because it allows not only to obtain an image of the external surface of the rope, but also to determine the diameter and pitch length of the rope on the basis thereof.

That method certainly belongs to visual testing (VT) methods and would complement the magnetic rope testing (MRT) method, especially where the latter is ineffective. This applies to steel wire ropes that do not reveal wear processes in the form of massive losses (corrosion, fretting and abrasion) and fatigue, and to a very large class of ropes made of artificial and natural fibres. That class of ropes is becoming more frequently used in areas where only steel wire cables were used previously. The presented method is currently the only proposed instrument-aided method for the evaluation of fibre ropes, in addition to the classic method of visual assessment.

2. CONFIGURATION AND RESOLUTION OF THE 3D VISION SYSTEM

Construction of a three-dimensional model requires proper configuration of the vision system and structural lighting to enable separation and reading of the data about the height of the profile of the tested rope components on the image in the camera. In order to conduct that task, a number of operating parameters of the checkpoint and of the vision system itself need to be determined (Kowal and Sioma, 2010, 2011; Gawlik et al., 2004). Measurement and evaluation of rope parameters should be carried out continuously along the entire length of the rope. This will enable assessment of the changeability in the determined parameters along the length of the rope and make it possible to assess changes in the selected parameters during operation of the rope.

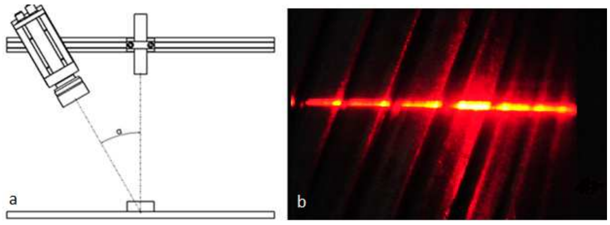

Fig. 3. Sample geometry of a 3D vision system and view of the laser line illuminating the rope

An example of 3D vision system geometry may be such an arrangement, as shown in Fig. 3, in which the laser plane is perpendicular to the axis of the rope. Optical axis of the camera is then inclined at angle α to the plane of the laser. Optical axis is the straight line passing through the centre of a camera's optical components and sensor (e.g. CCD) (Sioma, 2010, 2011a, b; Sioma and Struzikiewicz, 2011).

As a result of using such geometry, the plane of the cross-section of the object seen in the camera and produced by the laser beam is parallel to axis "Z" in the coordinate system of the test station, i.e. laser axis. Such a profile requires conversion of the geometry of the cross-section in the image created by the laser beam in order to obtain an actual three-dimensional cross-section, and then a three-dimensional image of the tested object.

In the next stage of vision system configuration, it is necessary to set the vision system resolution in the adopted configuration. As a result of change in object height, the laser line image moves on the CMOS camera sensor. Designation of vision system resolution consists in determining such minimum change in object height at which the laser image moves exactly by one row of pixels on the sensor. This is shown in Fig. 4.

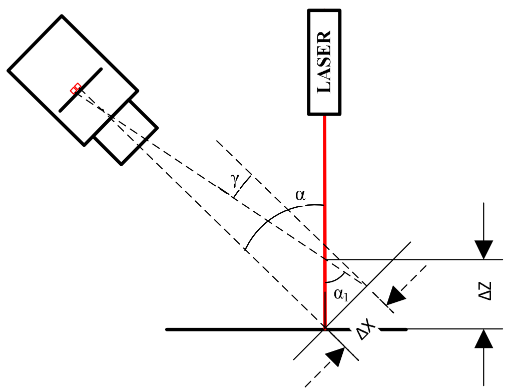

Fig. 4. Designation of the resolution of a vision system

Resolution ΔX in a plane parallel to the plane of the the sensor is determined based on the dimensions of the field of view and sensor resolution given in pixels in axis X. Resolution ΔY in axis Y is defined as the distance between the successive height profiles acquired on rope surface.

3. MEASUREMENT OF SELECTED ROPE PARAMETERS

For the inspection of selected rope parameters, a vision system was prepared to allow testing both in laboratory and typical working conditions. View of the station is shown in Fig. 5.

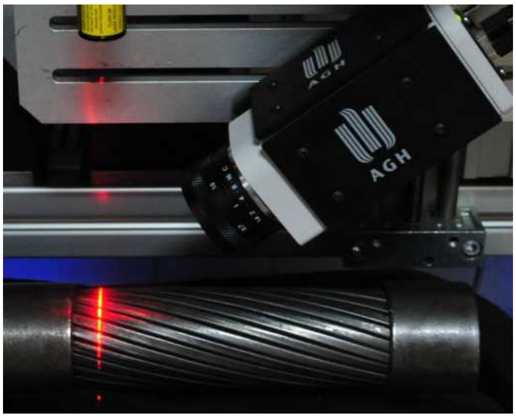

Fig. 5. View of the test station

The vision system receives an image on a monochrome CMOS sensor. Based on the sequence of images collected, height profiles of the tested object are determined in the successive cross-sections in accordance with the above-described resolution. Parameters of the vision system and the optical system are chosen in such a way that the image shows a trace of the laser line. It is also important that in the event of accidental reflection of laser light from rope surface, the trace of that reflection is not visible on the image. Based on parameters selected in such a way, successive images are acquired. Then, they are translated into a height profile to create successive cross-sections of the three-dimensional image.

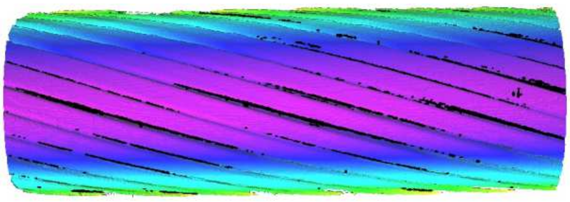

Fig. 6. 3D image of a locked-wire rope with "Z" wires in the outer layer

Both in the case of 3D profile and 3D image, there are distortions of the image resulting from both the geometry of the system as well as from the improper laser light reflection from the surface of the rope. This is shown by the example in Fig. 6. As a result of occlusion, the value of some of the points forming the 3D model of the object is equal to 0. As a result of laser light reflection from the edge of the object, the image shows interferences in the form of "height profile peak". Such an image must be pre-processed prior to any measurement procedures. The purpose is to remove any "false" measurement points. Fig. 7 shows an image after smoothing filtering using a structural element – a 3x3 sensor. However, it should be pointed out that in case of using the smoothing procedure, the height of "peaks" appearing in the image has an impact on the value of points in their vicinity. In addition, the plane passing through its axis was determined for the image of the rope. That plane is used as a reference plane in the measurements made on the image.

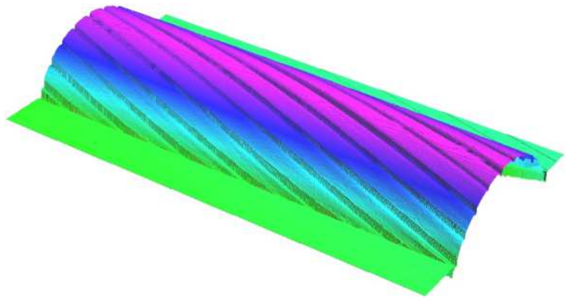

Fig. 7. Rope image after filtering

The presented method was used to measure the pitch length of the outer layer of a sample rope. Three-dimensional image was processed to determine the edges of strands forming the surface of the rope (Fig. 8a). The measurement was made by determining the distance between the edge of the same strand in the outer layer of that rope. The entire procedure was conducted for a twisted locked-wire rope with 23 wires in the outer layer. Pitch length was assessed on a continuous basis in order to determine the maximum, minimum and average length of the pitch along the rope.

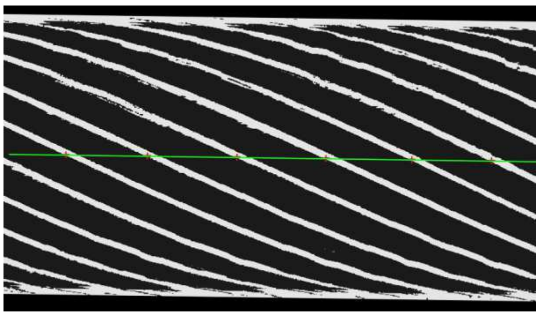

Fig. 8. Measurement of rope pitch length using an image of the edges of rope strands

The system is also equipped with a HMI, shown in Fig. 9, which enables presentation of the results of measurements and collection of measurement history for the purposes of follow-up documentation. Successive measurements of the pitch length of the outer layer of the rope are stored in a database and then processed and presented to the operator.

Fig. 9. Presentation of the result of rope pitch length measurements

Another parameter determined in the three-dimensional image of the rope is the diameter, as shown in Fig.10.

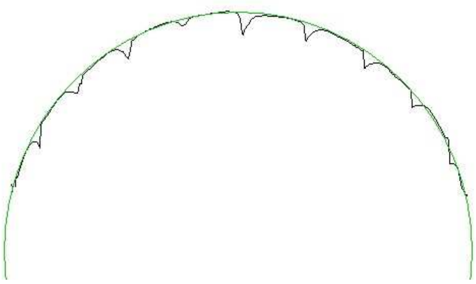

Fig. 10. Image of the cross-section of a locked-wire rope with "Z" wires in the outer layer

The diameter is measured in cross-sections spaced along the rope at distances of about 5 mm. On such a cross-section, a set of radii distributed over the profile every 1° was determined. Next, the maximum, minimum and average radius was determined for the tested cross-section. Rope diameter is determined as the diameter of the circle circumscribed on the profile shape and is calculated using the maximum radius. An image of the cross-section shows the shape of the outer layer of the rope and a circle representing the diameter determined.

Analysis of measurements allows determination of the average, maximum and minimum value for the tested ropes. It is also possible to promptly locate points on the rope that show a deviation from the limit values (e.g. permissible diameter tolerances) adopted for that type of rope.

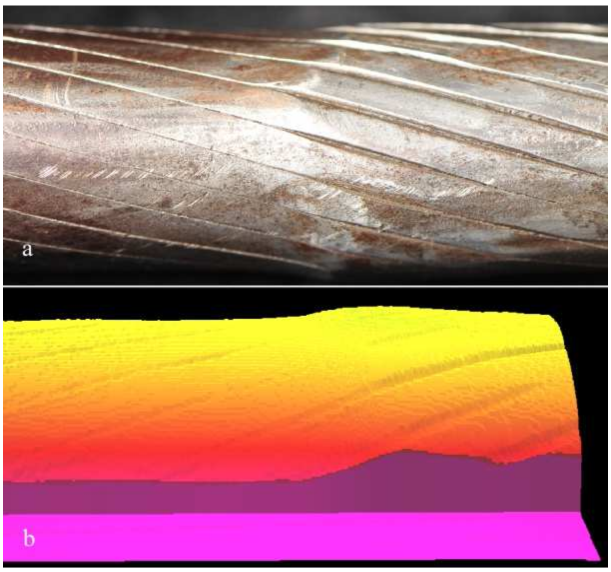

Fig. 11. View of rope section where a change in diameter was detected: a) view of rope, b) 3D image of rope surface

In the course of the study, an algorithm to detect defects on the surface of ropes was also developed. Some of the defects can be detected by measuring the diameter. A change in the diameter describes rope wear as presented in Fig. 11. However, defects associated with wire cracks should be controlled in a different way. For the purpose of such tests, an algorithm was prepared to detect continuity of the components making up the rope. Fig. 12 shows an example of a detected defect in the form of ruptured wire.

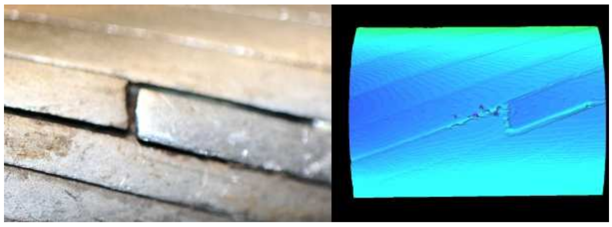

Fig. 12. View of ruptured wire in the outer layer of a FLCR-type locked-wire rope

4. SUMMARY

The above method, apparatus, and algorithm used for three-dimensional rope surface imaging with a laser warrants the following conclusions:

- it is possible to measure the length of rope pitch on any section of the rope;
- it is possible to measure the diameter on any section of the rope;
- the rope surface images obtained and the algorithms developed allow automatic identification of certain forms of damage and wear occurring on the surface of the rope;
- a sequence of diameter and pitch length values as measured along the rope allows for their registration as two additional diagnostic signals;
- recording of the results in computer memory or other storage media allows comparison of the individual parameters and changes therein in the rope service life function;
- the results of measurements obtained so far indicate that their accuracy is much higher than the accuracy of the current visual methods of measuring the geometrical characteristics of steel ropes.

It is expected that industrial implementation of a device for laser imaging of rope surface using a 3D method would allow the use of such a method as a supplement to the currently used magnetic rope testing and visual testing in the following applications:

- assessment of rope condition in hard-to-reach pulley systems, working port cranes, mining machines, off-shore equipment, etc.;
- replacement of visual assessment of the carrying ropes of cable railways with instrument-aided assessment using 3D imaging methods;
- supplementation of magnetic rope testing of all ropes with continuous measurement of diameter and pitch length;
- application of the 3D imaging method to assessment of the condition of ropes made of synthetic and natural fibres.

REFERENCES

1. **Bednarczyk J., Sioma A.** (2011), Application of a visual measurement technique to the assessment of electrodynamic stamping, *Solid State Phenomena*; Control engineering in materials processing, Vol. 177, 1–9, 20.
2. **Gawlik J., Ryniewicz A., Sioma A.** (2004), The strategies and methods of measurement in multifunctional quality inspection, *8th In-*

ternational Symposium on Measurement and Quality Control in Production, Erlangen, MEASURE AND QUALITY CONTROL IN PRODUCTION Book Series: VDI BERICHTE Vol. 1860, 649-662.
3. **Kowal J., Sioma A.** (2009), Active vision system for 3D product inspection: Learn how to construct three-dimensional vision applications by reviewing the measurements procedures, *Control Engineering* USA, Vol. 56, 46-48.
4. **Kowal J., Sioma A.** (2010), Metoda budowy obrazu 3D produktu z wykorzystaniem systemu wizyjnego [Construction of a 3D image of a product using a vision system], *Acta Mechanica et Automatica*, Vol. 4. No. 1, 48–51.
5. **Kowalski J., Nowacki J., Tytko A.** (2009), *Discard criteria for modern ropes in some applications*, OIPEEC Conference, Stuttgart.
6. **Sioma A.** (2010), Zastosowanie systemów wizyjnych 3D w kontroli jakości wykonania elementów pneumatyki i hydrauliki [Using 3D vision systems in the quality inspection of pneumatic and hydraulic components], *Pneumatyka*, No. 1, 27–30.
7. **Sioma A.** (2011a), Modelowanie i symulacja realizacji procesu technologicznego [Modelling and simulation of processes], *Mechanik* miesięcznik naukowo-techniczny, No. 12, 990.
8. **Sioma A.** (2011b), Projektowanie CAD z wykorzystaniem danych z systemu wizyjnego [CAD design using data from a vision system], *Mechanik* miesięcznik naukowo-techniczny, No. 12, 990.
9. **Sioma A., Struzikiewicz G.** (2011), Pomiary głowicy frezowej z wykorzystaniem systemu wizyjnego [Milling head measurements using a vision system], *Świat Obrabiarek*, No. 9-10, 8-10.
10. **Tytko A.** (2003), *Eksploatacja lin stalowych* [Utilization of steel wire ropes]. Wydawnictwo Naukowe „Śląsk", Katowice – Warszawa 2003.
11. **Tytko A., Sioma A.** (2011), Evaluation of the operational parameters of ropes, *Solid State Phenomena*, Control engineering in materials processing, Vol. 177, 125–134.

Acknowledgement: The work was done under research project no. N N502 337336 funded by the Scientific Research Committee.