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MODEL OF NON-LINEAR WIRE ROPES FATIGUE PROCESS

The paper concerns on fatigue behaviour of steel wire ropes. Wire ropes are used in many transportation machines and systems. Reliability of such systems depends also on ropes which degrade during service time. Understanding of degradations processes plays important rule in wire rope use. One of such ways is simulation using mathematical models of degradation processes. Paper presents an idea which allows modelling and predicting the wire rope fatigue process. The wire rope fatigue damage is modelled using computer environment on the basis of Miner and Palmgren's hypothesis and Wohler's fatigue low that allows for determining the life of individual wires in wire rope bunch structure. Basic equations are represented by non-liner functions. The paper presents only the main idea in which digital model is computed. The results are plotted as time/cycle functions of number of broken wires as rope life curves. The model affords a good agreement between theory and practice and allows modeling different situations with changeable parameters of wire ropes and loading.

1. Introduction. The paper presents an idea which allows modeling and predicting the wire rope fatigue process. The wire rope fatigue damage is modelled using computer environment on the basis of Miner and Palmgren's hypothesis and Wohlers fatigue low that allows for determining the life of individual wires in wire rope bunch structure. Both equations are represented by non-liner functions. When a single wire of the-rope breaks, the carried load is redistributed among the remaining wires. Later then the second wire breaks and process is continued until the rope discard criteria are rejected. The paper presents the main idea in which digital model is computed. The results are plotted as time/cycle functions of number of broken wires as rope life curves. The model affords a good agreement between theory and practice.

2. The fatigue behaviour of wire ropes. The fatigue of wire ropes in service on different drive transport facilities and other installations is one of the most important reasons of their discard. After number of cycles broken wires occurs and wire rope have to be replaced with a new one. The problem is that the fatigue behaviour of a wire rope of specified construction used in given service conditions cannot be precisely determined on the basis of such data as rope construction, mechanical properties of wires and the manufacturer's specification of loading. This parameter can be only approximated. There are several definitions of the fatigue endurance of wire ropes. The most convenient definition of the fatigue endurance is the number of work cycles for the given rope in specified environmental and fatigue conditions. This parameter can be well used to compare various rope constructions used in similar applications. In publications [3] on the subject several techniques of determining the fatigue endurance is suggested. Generally speaking, three approaches are possible: calculation of the allowable number of cycles (using very complex formulas), the use of testing fatigue machines and having data from wire rope service taken during periodical inspections. This method is preferred by the author.

The first technique lacks precision; the formulas are rather extensive and fail to take into account the random factors. Still the method is used in Germany (by CASAR rope manufacturer), England and France to assess the fatigue endurance of ropes in new applications. The second method involves complicated, time-consuming and expensive endurance tests on various testing machines. The results are mostly reliable though there are some restrictions too: as the tests have individual character the results must not be generalised, hence standardisation becomes a major problem. Besides, tests last a long time and are subject to limitations resulting from testing machine structure, so the scope of tests that might be performed is usually limited. The last one technique is not practical because of very long time of gathering information but it gives very interesting results. This function is practically useful only for particular type of rope construction and installation.

Though the fatigue endurance of wire ropes can be determined this way, this parameter still is difficult to interpret, especially for wire ropes being still in service. It is a well-known fact that ropes in multi ropes hoists friction winders having the same construction, produced by the same manufacturer and used in the same environment will behave differently. Such observations lead us to the conclusion that the effects of random factors on stress distribution patterns in ropes are far from minor, though sometimes tend to be overlooked. Stress variations in single wires cannot be monitored experimentally; hence the Author suggests that this phenomenon be studied by way of computer modelling of rope construction, loading and random factors. Results of computer simulation allow for determining the effects of stress distribution in ropes on fatigue endurance of the whole rope installation. Several simplifications and limitations being considered, it was demonstrated that creation of such a model is possible and thus generated results allow for highlighting several random processes- a thing that has not been done so far.

3. Simulation of non-liner fatigue process of wire ropes. The mathematical model for simulation includes several rules as well as simplifications and restrictions written in the form of an algorithm in Matlab [1]. The main aim is to compute the service life (or number of cycles) of subsequent wires till their fatigue failure. The block algorithm is shown in figure 1 and more precisely is explained in paper [3].

Rule 1. All wires are loaded with external loading forces. These loads as well as other forces or moments of force generate the complex state of strain in the rope, depending on rope geometry (at that stage contact and tangent stresses are neglected). Each wire is described with the parameters: diameter d, R_m and a way of manufacturing.

Rule 2. Stress distribution in wires is random though the sum of axial responses (along the rope axis) to loads carried by individual wires is always equal to the external loading.

Rule 3. Wires are subject to fatigue, manifested as brittle cracking due to cyclic fluctuations of external loading. The fatigue of wire material is derived from the non-linear S-N formula, specific for each wire. The coefficients in the S-N formula may be random.

Rule 4. The number of cycles to the wire rupture is obtained from the summation non-linear formula (1) developed by Miner [2] and Palmgren.

Rule 5. Highly stressed wires break first, after being in service for the ultimate number of cycles, obtained from the S-N non-linear formula (2, 3).

Rule 6. When a wire breaks, the load it carried is redistributed among the remaining wires in proportion to their earlier loading

The normal distribution pattern is applied in modelling of random parameters and variables present in the algorithm. Some tests reveal that the normal distribution provides a good estimate of the real stress distribution and so do the Reilegh and Weibull's distributions.

Each rope wire is subject to fatigue wear which has a cumulative character. Working time of each wire is defined by the number of stress cycles and the stress amplitude for a given number of cycles. It is described by Miner Palmgren's [2] as equation (1):

$$\sum_{i=1}^{i=j} \frac{n(i,j)}{N(i,j)} = \sum_{i=1}^{i=j} \alpha(i,j) = 1. \qquad (1)$$

Where: *i* is the identification number of the broken *wire*, *j* is the identification number of the wire, *n(i,j)* is the number of stress cycles the wire worked loaded with the stress of s*(i,j)*, *N(i,j)* is the number of stress cycles under after which the wire breaks under stress *s(i,j),* a*(i,j)* is the ratio of the *n(i,j)* to *N(i,j)*.

Wohlers equation is usually presented as non linear formula (3) which could be presented in linear form as (3). Parameters for linear equation are usually known from fatigue tests for wire rope wires:

$$N \cdot \sigma^{b} = c\,, \tag{2}$$

$$\log(z) = c + b \cdot \log(N). \tag{3}$$

Where *N* – is the number of stress cycles under after which the wire breaks under stress s, MPa, *c* – constant, *a, b* – Wohlers equation constants.

3. Rope endurance simulation. The model facilitates assessment and quantification of influence various parameters have on rope endurance. The discussion that follows is confined to relations between type of load distribution in rope wires and rope life. While these specifications do not reflect any specific rope, they allow for assessment of model performance for a variety of changing parameters for example: the carried load (figure 2).

The rope endurance was simulated for varying load distribution and parameters taken from practice. In the first run rope was normally loaded. In next two runs the rope was under loaded (10% less then normal load) and overloaded (20% more). Under loading or overloading has very important influence on further shape of wire rope endurance curve. In the modelled situation the rope remained in service for 56,000 cycles and the fatigue wear index reached 5 % loss of metallic cross section. Afterwards an increased load was applied, 10 % higher than the initial value. In the second case modelled here the load was relieved by 10 % with respect to the initial value. This figure gives an idea about results which could be obtained using mathematical modelling of wire ropes damage which can solve difficult to other analysis non-linear problems.

4. Conclusions

1. Having applied the fundamental principles of describing rope geometry, the techniques of wire manufacture, the fatigue formula, the cycle cummutation formula for individual wires and some rules governing load distribution among the wires, one can develop a model of fatigue wear which allows for simulation of these processes on any PC computer platform.

2. The model allows for simulation of effects of parametric and non-parametric factors related to random properties of the material constants, particularly the random character of load distribution and redistribution and stress per single wire.

3. The model helps to analyse how several factors, not considered hitherto, should affect the fatigue endurance of wire ropes.

4. Simulations utilising the fatigue wear model allow for optimisation of rope design as excellent endurance parameters can be achieved.

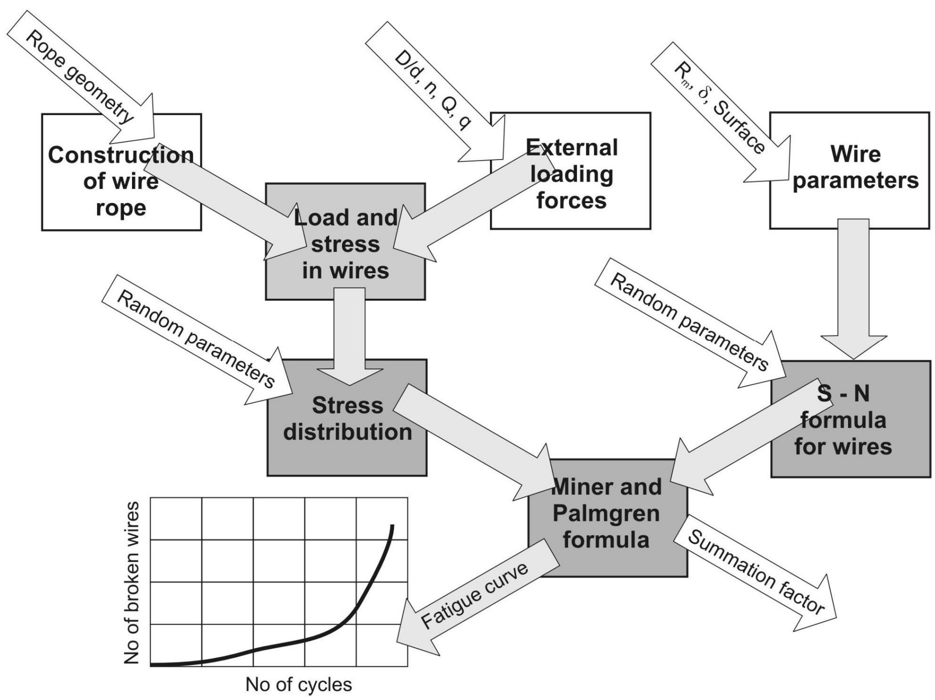

Figure 1.
The block algorithm for calculation wire rope fatigue endurance

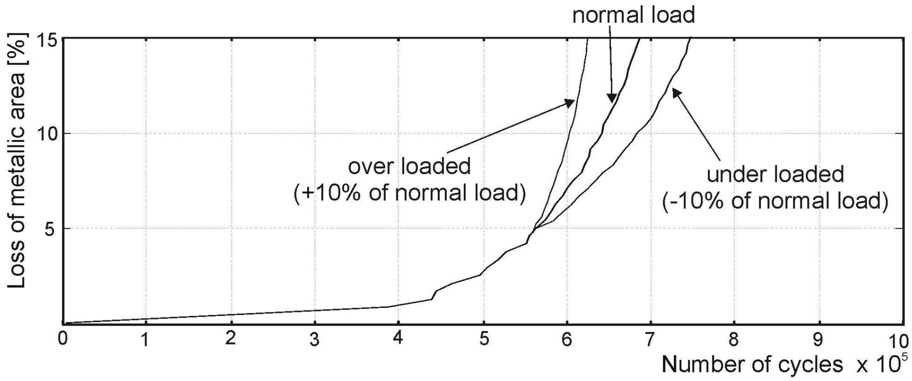

Figure 2. The influence of the change of load during wire rope service on its lifetime curve

5. The applied calculation procedures allows for identification of factors which influence rope quality in a minor degree.

6. Despite several simplifications and limita-tions, the results of fatigue wear simulations are consistent with the results of rope testing on testing machines and in real-life conditions; hence the simu-lation results might be used in qualitative analyses.

7. The model has a great educational value, it allows for quick monitoring of the influence of several factors on the fatigue endurance of wire ropes.

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Резюме

Көлік жүйелерінде және құрылымдарда қолданылатын болат арқандардың тозу процесі зерттелген. Мұндай жүйелердің жұмысының сенімділігі эксплуатация кезінде тозатын арқандардың жағдайына байланысты болғандықтан, өте маңызды роль атқарады. Minera Palmgrena жорамалы мен Wohlera теңдеулері негізіндегі компьютерлік симуляция шаршап тозу процестерін зерттеу әдістерінің бірі болып табылады. Бұл әдіс болат арқан құрылымындағы жеке болат жіптердің жұмыс уақыттарын анықтауға мүмкіндік береді. қолданылған теңдеулер сызықты емес. Мақалада есептеу модельдерінің негіз-дері беріліп, алынған нәтижелер график түрінде берілген. ұсынылған нобай тәжірибемен сәйкес келеді, сонымен қатар болат арқан және олардың жүктемелері геомет-риясының айнымалы параметрлерінде түрлі есептеулер жүргізуге мүмкіндік береді.

Резюме

Рассмотрена проблема усталостного износа стальных канатов, повсеместно используемых в транспортных системах и оборудовании. Надежность работы таких систем зависит также от состояния стальных канатов, которые изнашиваются во время эксплуатации, поэтому понимание этих процессов играет здесь огромную роль. Одним из методов исследования является компьютерная симуляция с использованием моделирования и прогнозирования процесса усталостного износа на основе гипотезы Minera Palmgrena и уравнений Wohlera. Этот метод позволяет опре-делить время работы отдельных стальных нитей в структуре стального каната. Использованные уравнения имеют нелинейный характер. Приведены основы вычислительной модели, а некоторые результаты компьютерной симуляции представлены в графическом виде как функция нарастания числа усталостных изломов в зависимости от количества циклов работы. Предложенная модель дает хорошее согласие с практическими наблюдениями и позволяет проводить различные моделирования ситуаций с переменными параметрами геометрии стальных канатов и их нагрузки.

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