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Wire ropes NDT discard criteria based on life-time prediction model

1. Introduction

Wire ropes discard criteria that need to be applied to prevent failure belong to following main groups. First one refers to empiric fatigue life-time regression model defining the number of tension/bending cycles until rope breakage as function of operating parameters [1]. That sort of expressions may be used for fatigue life prediction of idealized rope at design stage of the load lifting machine.

Second group implies discard standards related to limit values of typical defects, most often to limit number of wire breaks on a reference length [2]. These criteria are used if any diagnostic information about the instant degraded state of the particular rope is available. This approach is suitable for individual rope life-time prediction during practical operation.

Evident dependence between number of fatigue cycles and amount of broken wires was found out by laboratory tests in special situations [1]. But relations of this kind are of little use in practice because of the multitude of factors acting on the rope endurance in real duty. So it is difficult to combine the on-line diagnostic information with common empiric life-time formulae. If only NDT data are available, the problem of rope retirement lies in proper interpretation of these data from the strength point of view.

- Magnetic rope testing is the most commonly used diagnostic method for wire ropes [3]. Magnetic flux detectors measure two kinds of rope defects – distributed losses of cross-sectional metallic area (LMA) due to abrasive/corrosion wires wear and localized faults (LF) such as wire breaks. These data correlate with the endurance of degraded rope, but they do not indicate its strength in the quantitative sense. The question is that standard discard criteria do not account for combined action of that sort of defects on rope's strength. Furthermore, LMA and LF rates may differ significantly so it is difficult to predict life-time of the rope and make decision on its discard by two diagnostic indicators.

• Aim of study is to develop a new way of looking on wire ropes discard problem. An idea is to consider LMA and LF diagrams as input data for appropriate rope's mechanical model to obtain the generalized parameter that specifies the rope varying degradation rate. The stress safety factor seems to be a proper indicator for estimation the technical state of degraded rope and also for predicting the instant life-times during the operating history of individual rope. Assumed discard criterion refers to remaining life-time calculated regarding the permissible strength level of deteriorated rope under investigation.

2. Predicting the wire rope strength using magnetic NDT data

Strength decrease of rope in service may be simulated using the results of regular periodic rope inspections. NDT data – the metallic cross-sectional loss ΔA and number of wire breaks B are input parameters for mechanical model of degraded rope. The residual strength of the rope is estimated by stress criterion in wires. This gives a stress safety factor $n(\Delta A, B)$ which depends on NDT data. Normally this parameter is defined as minimum value out of safety factor under single loading and fatigue safety factor [4]. Because measured NDT data do not account for the distribution of faults over wires, and are in general of a random nature, the statistical modeling of wear locations in the rope cross-section has been performed. So the stress safety factor is treated as a probabilistic indicator of rope strength state. The details of procedure and the features of mechanical model are described elsewhere [5, 6].

• Loss of metallic area ΔA and number of wire breaks B are varying along the rope line with operating time. Assume the stress safety factor $n(x,t)$ to specify the residual strength in the rope cross-section with longitudinal coordinate x at time t. Parameter $n(x,t)$ may serve as discard indicator of deteriorated rope. The safe state condition of the rope at operating time t is given by

$$\min_x n(x,t) \geq [n]. \qquad (1)$$

The permissible safety factor $[n]$ defines the rope's margin of survivability as for partially failed structure. It may be determined from rope lifetime experiments or estimated regarding corresponding normative rules.

• When condition (1) does not hold, this signifies rope's failure. More adaptable discard criterion may be set with respect to the remaining lifetime of degraded rope right away the last inspection. Rope's near future depends upon answering three questions:

1) Whether to stop or to continue the work of the rope at the achieved operating time, factoring in all previous inspection history?

2) If the decision is to continue, at what operating time should the next examination be conducted and what value for safety factor is then expected?

3) What operating time does it left for the rope regarding ultimate "vital" factor$[n]$?

To reply one should have a theoretical model for planning regular inspections and for predicting the rope lifetime by strength history, which, in turn, is a sequent of NDT history. In this study life-time prediction model is based on the least-square extrapolation from several previous safety factor estimates to permissible level. Forecasting procedure is being adjusted for instant degradation rate and proximity of current safety factor to ultimate value$[n]$. Details of algorithm are described in [7].

3. Examples

• The cargo crane non-rotation resistant rope PYTHON 8xK19S+PWRC(K) 2160 B sZ was five times examined by magnetic device INTROS under tension-bending fatigue loading. Rope's diameter – 8 mm, sheave diameter – 350 mm, nominal tension – 10 kN, tensile strength – 2160 MPa. Any noticeable losses of metallic area were not detected. The wire breaks have been revealed only since the third inspection. The 3^{d}, 4^{th} and 5^{th} LF charts are shown in Figure 1. Processed LF-data were imported to rope strength programming code and corresponding distributions of safety factor along the rope distance (x – coordinate) have been evaluated (Figure 2).

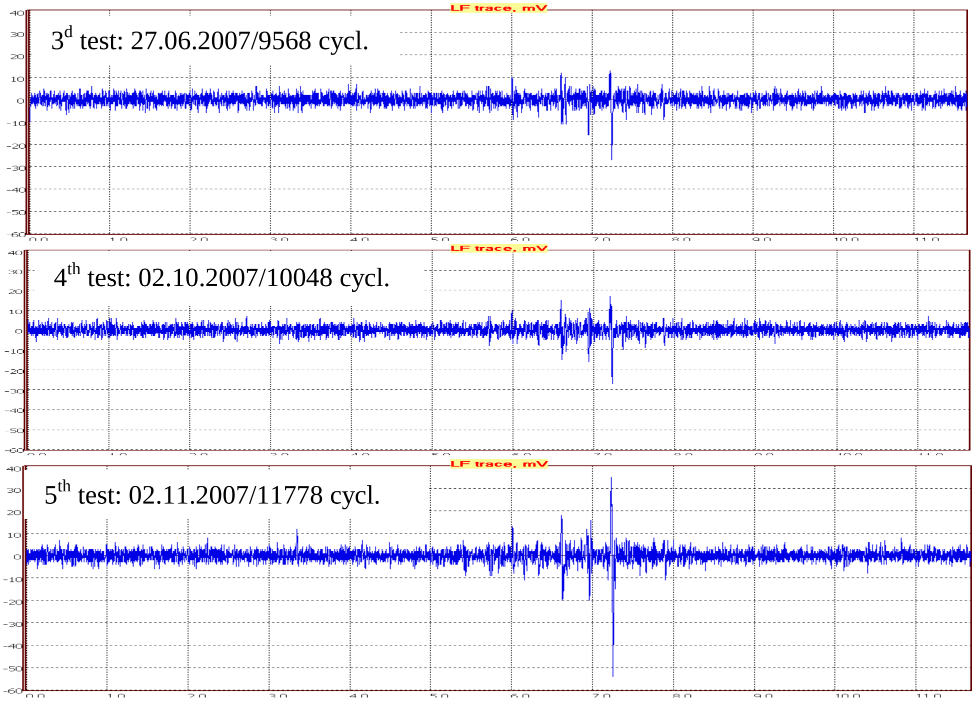

Figure 1. LF charts for lifting crane rope PYTHON D8

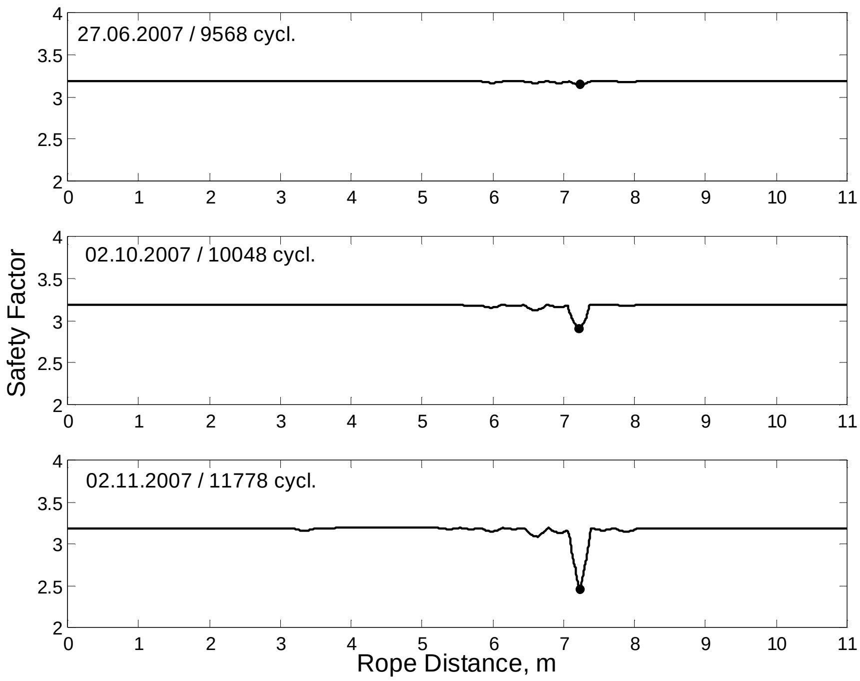

Figure 2. Time-quantified safety factor distributions along the segment of crane rope PYTHON D8

Safety factors have been calculated in each rope cross-section with given number of wire breaks by averaging over 100 samples with an assessment reliability of 0.997. Local faults indicate the interval where rope failure develops and will probably occur. The minimum values (marked as circles) may be adopted as implicit discard parameters of deteriorated rope. Also they serve as rope state indicators for planning the dates of next inspections and predicting the remaining life-time. Here and below the number of operating (loading) cycles is considered as the operating time t.

• Figure 3 demonstrates the changes in both the minimum estimates and expected values for planned inspections as piecewise-linear functions of operating cycles for all NDT history of the rope. The non-defective rope has the safety factor of 3.2. The permissible level $[n] = 1.5$ was evaluated with respect to normative LF-standards for rope type under examination [8]. Planned quantity of operating cycles to the next inspection is equal 13508 with expected safety factor of 1.91.

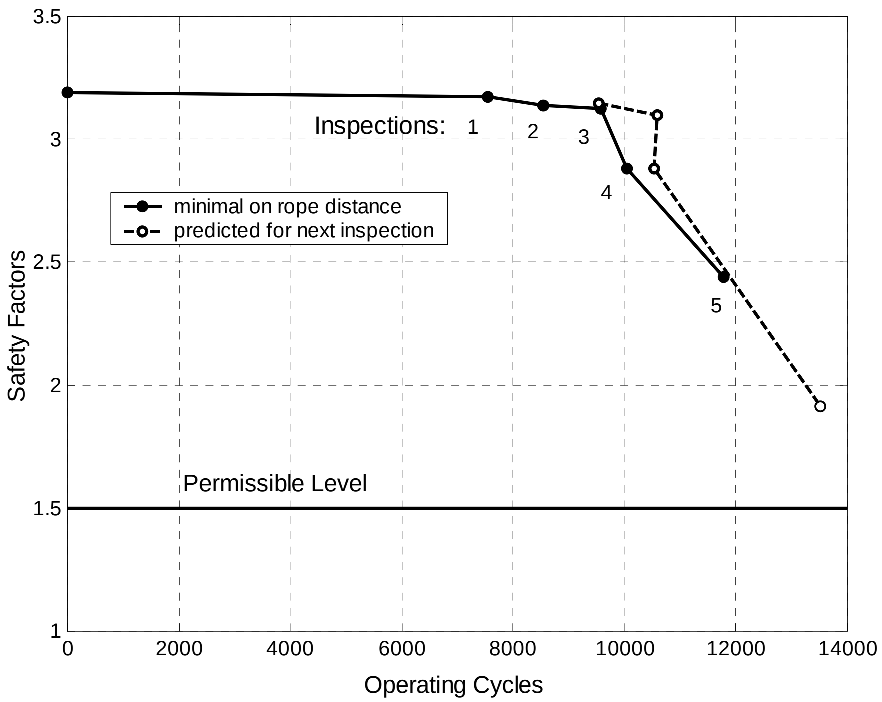

Figure 3. Changing of instant safety factors and prospective estimates for deteriorated crane rope PYTHON D8

Predicted remaining life-time tendency of progressively degraded rope is presented in Figure 4. Numerals near markers denote the numbers of inspections which data served as input parameters for rope strength model. Forecasting procedure starts after second testing when at least three safety factor estimates are available. After the last inspection the rope could have reached a defined discard condition of 1.5 in 2850 operating cycles. That rope was not reduced to failure so its real life-time is unknown.

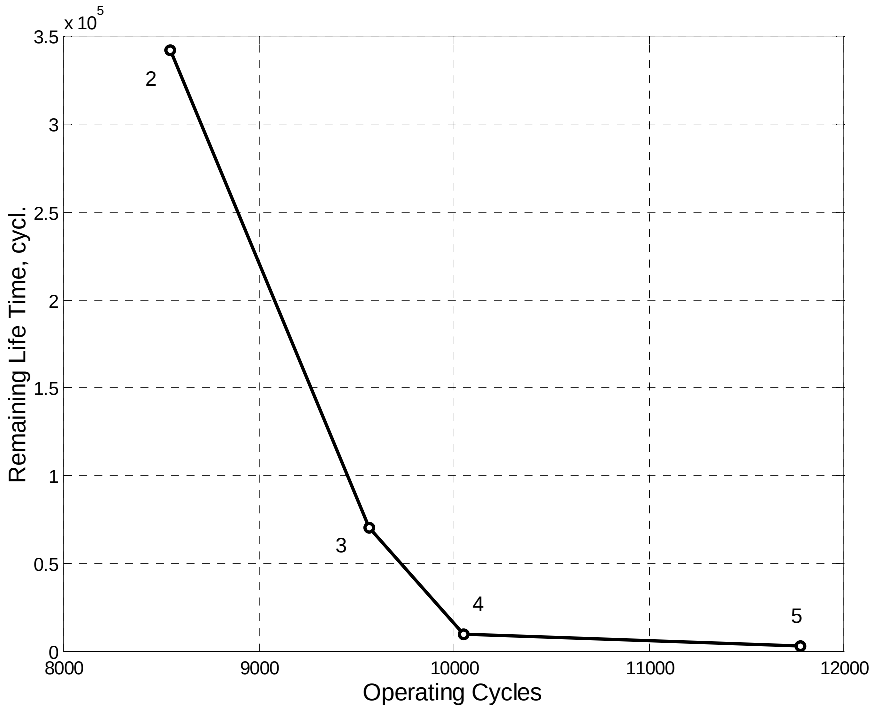

Figure 4. Remaining life-time estimates for crane rope PYTHON D8.

Note that theoretical prediction must be treated only as a proposal for the rope inspector, who is the only person to make the final decision concerning the technical state of the rope and what future actions should be undertaken.

• Next example relates to rotation resistant rope DIEPA 15xK7-WSC 1315 subjected to swivel conditions in jib crane at offshore Sakhalin platform. Rope diameter is of 32 mm, nominal tension – 162 kN, tensile strength – 2160 MPa. Series of LMA and LF charts measured by NDT device INTROS are presented in Figure 5. Only one broken wire was detected at 149.6 m but increasing reduction of metallic cross-sectional area may be recognized in tested distance.

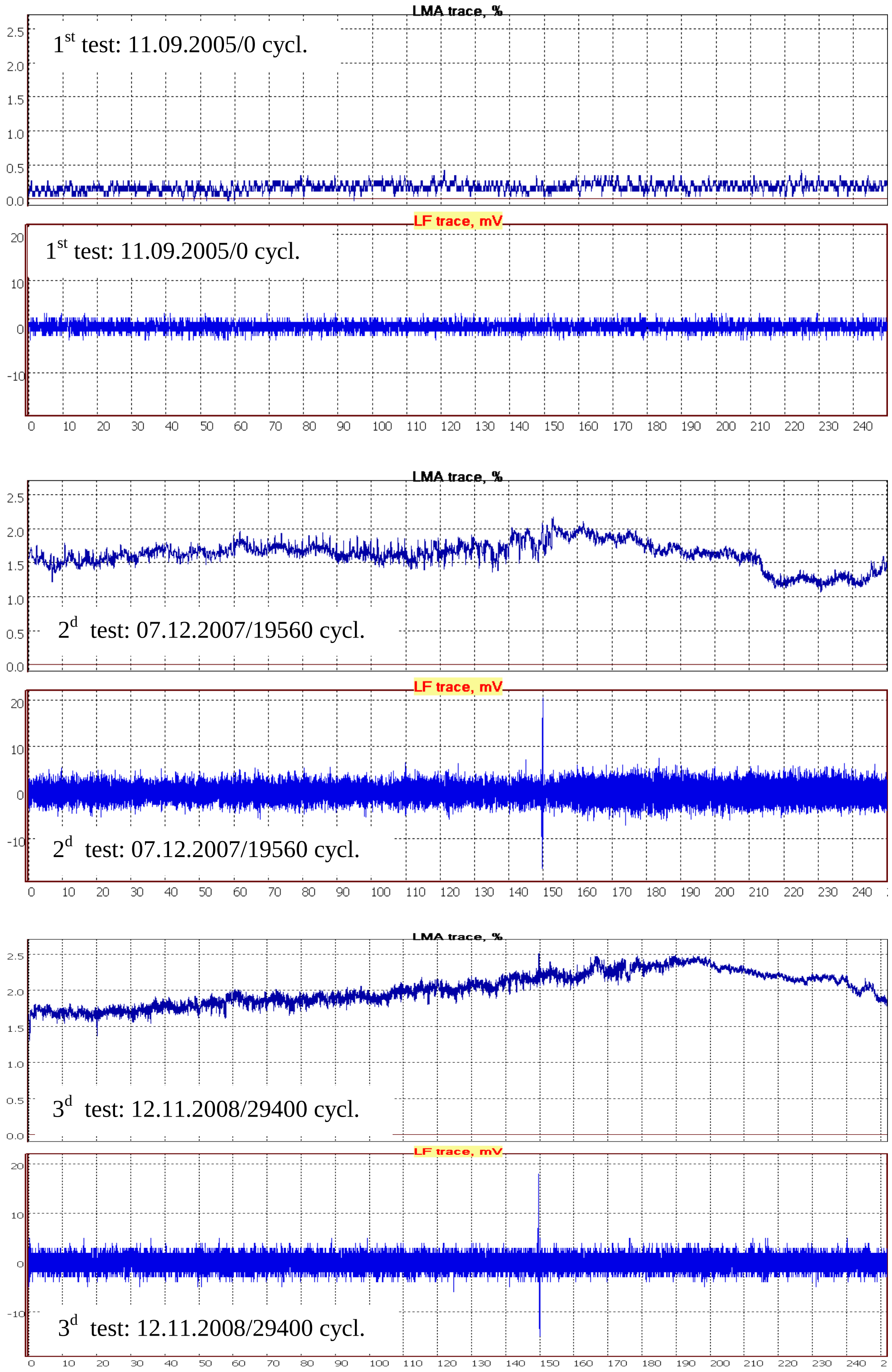

Figure 5. Successive LMA and LF charts of rope DIEPA 1315 D32

Corresponding rope strength estimates are shown in Figures 6 and 7. The rope is still reliable in operation because the degradation is mildly sloping as yet so that factor of safety keeps above the discard (permissible) level of 3.5.

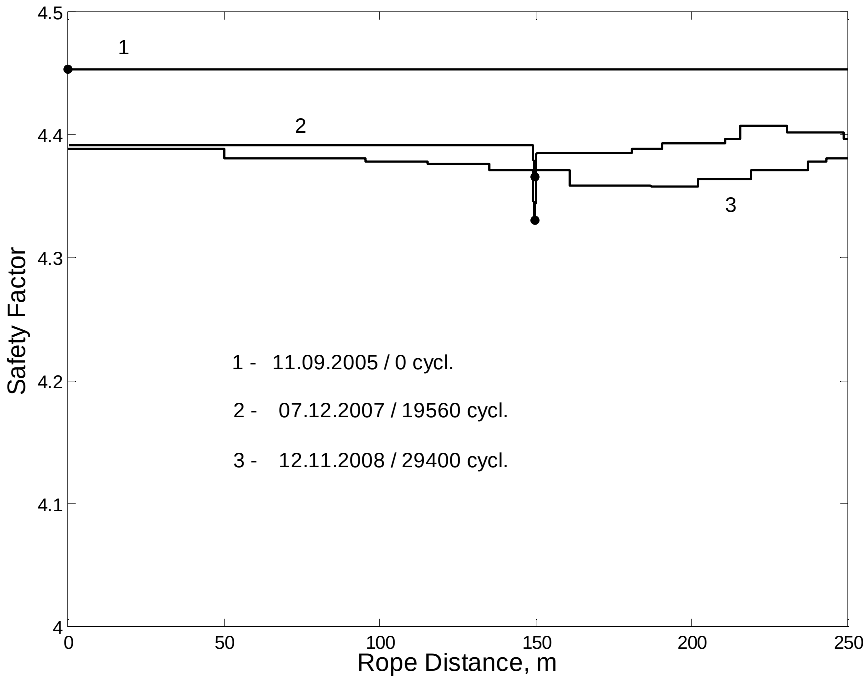

Figure 6. Safety factor distributions along the segment of jib crane rope DIEPA 1315 D32

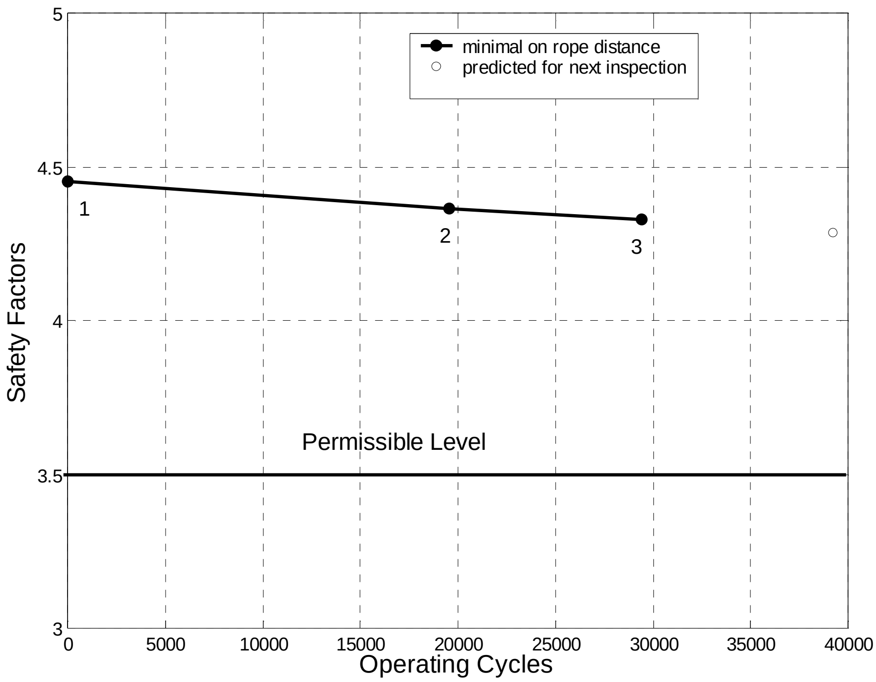

Figure 7. Changing of instant safety factors and predicted testing for deteriorated rope DIEPA 1315 D32

Next inspection is planned on 39240 operating cycles with expected safety factor of 4.29 (light circle in Figure 7). Present remaining life span has been predicted around of 195300 operating cycles with regard to given permissible level.

4. Conclusions

- The strength assessment model using magnetic NDT data estimated accurately the strength state of the tested ropes. It may be used for wide range of ropes constructions and service conditions.

The proposed approach increases the reliability of rope inspection because the successive test dates are dependent upon the condition of the rope. NDT-mechanical-discard procedure is adapted for particular rope subjected to specific working conditions. In practical use the predicted diagnostic times and working life spans give the NDT operator further information that will help in making a valid decision on testing and unfailing maintenance policy.

5. References

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