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HIDDEN SEQUENCES IN RESULTS OF TESTS IDENTIFYING

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Abstract. *Describes a method and a general algorithm for the experimental data series corresponding to a given recurrence relation search program. Search-analytical model different from the existing search models is offered.*

Keywords: confidence intervals; recurrence relation; search model.

1. Introduction

For experimental data analytical processing it is often necessary to distinguish the data array corresponding to certain regularity from the set of data. In case of specific group of common data set selection cluster analysis is used. It allows to classify the test results belonging to a small number of generalizing results. However, cluster analysis does not reveal sequence including periodic of the complex process results data. For example, such problem can arise when it is necessary to determine hidden sequences in the results that are represented in broad statistical aspect.

2. Analysis of researches and publications

In current approaches of the fatigue process studying is considered that the change of the physical and mechanical properties of the specimens or structure with cycling loading has gradually and monotone character. However, the work carried out as two-stage loading fatigue tests [Radchenko, Sultanov 1977] showed the residual life (n_2) oscillation for certain values of the prior cycling (n_1). This rapid residual life increasing is called as "spikes".

Analysis of two-stage loading test results, performed in the statistical aspect showed, that the residual life spikes occurrence is not accidental. They form a series that can be described by the recurrence relation proposed by V. Ivanova [Ivanova, Terentev 1975].

Position of the residual life first spike for each series is characterized by the number of prior loading cycles n_1 up to the first (base) bifurcation point and depends on the material under study, as well as the level of cyclic stresses. Position of other spikes in the series can be calculated by the formula:

$$\frac{n_1(i)}{n_1(i+1)} = \Delta^{\frac{1}{2^{i-1}}}, \qquad (1)$$

where n_1 – number of cycling loads, that determined bifurcation points appearing;

i – sequence number of bifurcation points;

Δ – metal fracture universal constant, that can be calculated as

$$\Delta = \frac{L}{H_0} \cdot \frac{G}{E},$$

L – Latent heat of fusion;

H_0 – change in enthalpy under heating from 0 degrees K to fusion temperature;

E, G – modulus of elasticity and shear modulus with 0 degrees K.

For aluminum metal fracture universal constant **Δ** = 0,225, for iron – 0,108, for cooper – 0,168.

In work [Radchenko et al. 2008] flat compact specimen (100 × 10 × 1,0 mm) of D16T aluminum alloy were rigid loaded at the fatigue machine that permits cyclic symmetric cantilever bending.

During first stage loading (prior cycling) the amplitude of the cycle in control area of the flat specimen was equal to σ_a = 79.5 MPa. The stresses at all points of the specimen cross-section were constant.

After predetermined number of prior loading cycles n_1 it was in the specimen 1.2 mm diameter hole on an axial line at a distance of 4 mm from the clamp (concentration factor is k = 3) drilled. This leads to a nonlinear stress redistribution in the cross-section. In this case, the stress on the edge of the cut has the greatest value (σ_2).

Fatigue crack initiated at the edge of the hole.

The fracture took place after n_2 cycles. The value of the residual life n_2 indicates the material properties change under fatigue (Fig. 1).

As can be seen from the Fig. 1, the correlation field n_1-n_2 is complex. In work [Radchenko et al. 2011] proposed to consider the data field n_1-n_2 as a combination of two processes: low and high frequency process.

High-frequency process characterized by the spikes set. In the process of cyclic loading can be observed the appearance of several series of spikes that form a cascade series. These series of spikes can overlap each other, complicating their recognition.

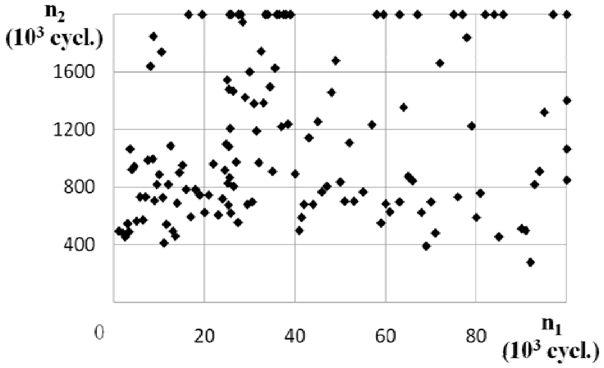

Fig. 1. Correlation field n_1-n_2

Furthermore, during the fatigue test it is likely to miss spikes, which also complicates the identification of the series.

It should also be noted that the use of non-destructive inspection methods: micro-hardness [Radchenko, Korchuk 2002], resonance-contact method [Pisarenko et al. 2008] were noted changes in the oscillation of the controlled parameters under cycling loading of materials. Therefore, the task of studying changes in physical and mechanical properties under cyclic loading is closely associated with the identification of hidden sequences, that is connected with the each series of spikes identification.

The aim of work is to develop algorithms that identify hidden sequence in the research findings.

3. Search model algorithm

For the hidden sequence educing in case of large test data level, that has been described early, it is easy-to-use program Poisk-2 developed in a numerical computing environment Matrix Laboratory.

Algorithm is based on series of the features that will be described below.

Series of spikes position is characterized by number of cycles $NB_{c,1}$ (basic bifurcation point of c-series), that is correspond to the first spike in c-series. Value of $NB_{c,1}$ is random variable.

Next numbers $NB_{c,i}$ are also correspond to bifurcation points of fatigue process position that will lead to the spikes appearance. Thus certain series of bifurcation points that are precisely interconnected with $NB_{c,1}$ by recurrence relations (1) is formed.

The first feature of row that is based on relation (1) is interval between bifurcation points decreasing up to the last points of row (Fig. 2). It complicates the task of all members of the series with the two-stage cycling method identifying because in this case, the test should be conducted with a very small step (number of prior loading cycles change). This problem is more typically for the small value of $NB_{c,1}$.

The second feature of the test data is the censored series presence, i.e. the series, which do not have the first few points (censored on the left) and the series which do not have the last few points (right censoring).

In the first case, spikes occur during first cycle loading, when the stress in the specimen increases from $\sigma_1 = 0$ to σ_{1max}. In the second case, the last spikes can't be detected due to the limited boundaries of the prior loading cycles test area n_{1max} or testing base.

The third feature of the test data relates to the nature of the fatigue process evolution. Spikes of c+1 series arise before the end of the previous c-series. This results to the "random" experimental sequence of spikes, and only the use of special methods of the hidden sequences identification in the test results provides valuable information on the nature and character of the process.

According to this features the algorithm of sequences searching program (Fig. 3) is based on next principles.

1) The value of prior cycling, corresponding to the first base bifurcation point is defined by user. Fig. 4 shows an example of the base bifurcation point $NBT_{r,\ i}$ (▲) position determining, calculated for four series. For the first row (r = 1) position of the base bifurcation point is determined by $NBT_{1,1}$ = A number of cycles.

2) During hidden sequences searching the base bifurcation point of calculated row (NBT_r) will "slide" with n_1 = S increment, which is also specified by the user. This means that the position of the base bifurcation point of calculated r-raw ($NBT_{r,\ 1}$) will be shifted from the first ($NBT_{1,\ 1}$) on (r-1) × S cycles.

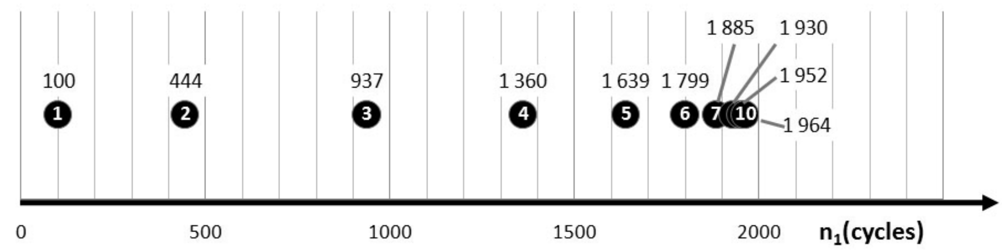

Fig. 2. Position of Bifurcation points in calculated row for $NB_{c,1}$ =100 cycles

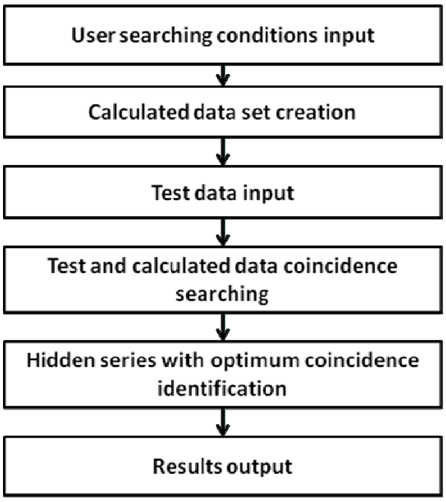

Fig. 3. Program algorithm

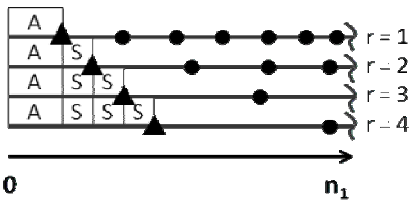

Fig. 4. Diagram for the base (▲) and next (●) bifurcation points position determination

3) Test data spike has coincidence with a calculated row spike $NBT_{r,i}$, if the absolute value of their difference is less than the confidence interval $\varepsilon_{r,i}$.

In Fig. 5 several cases for a calculated r-row are considered.

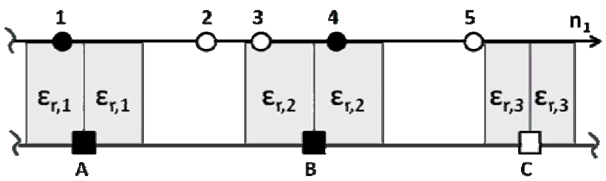

Fig. 5. Schematic diagram for the bifurcation points hidden series identification: test data with (●) and without (○) coincidence with the calculated row; calculated data with (■) and without (□) coincidence with the test data

The numbers from 1 to 5 marked a test data bifurcation points. The letters A, B and C denote the first three points of the calculated r-row. For each spike of the calculated row the check zone boundaries specified and defined by confidence intervals $2 \times \varepsilon_{r,\,i}$.

It should be noted that the size of the confidence intervals is defined by the user and depends on calculated row bifurcation point position.

This is due to the fact that the change in the distance between the points in accordance with equation (1) is complex (Fig. 2).

According to this approach, it may be few spikes in the boundaries of the check zone. In this case, the program determines the spike with the smallest deviation from the calculated value.

Analyzing presented in Fig. 4 case can be noted:

– for the base bifurcation point A of the calculated row has coincidence with the test data spike. Point 1 is to the left of A in the range $\varepsilon_{r,\,1}$.

– in the check zone boundaries of calculated row second bifurcation point B are located test data points 3 and 4. Program algorithm is developed in such way that the coincidence point will be the point with the smallest deviation from calculated point. In our example, this is point 4.

For the calculated point C there is no coincidence with test data points, as the nearest point 5 lies outside the check zone boundaries $2 \times \varepsilon_{r,\,3}$.

4) The row is detected if the number of determined spikes is equal or greater than user-specified spikes number.

5) However, it's possible that the number of a coincidence for the same spikes will be identical. It may be in case of a small S-value or a large value of check zone boundaries user selection. For this purpose, program choose series with the smallest total value of the standard deviation;

Table illustrates the results of hidden sequences identification derived from the data of [Radchenko et al. 2008], which are represented on Fig. 1.

Table form and the coincidence error value representation allow to determine the area of calculated NBT and test NB values intersections and optimize user searching condition input.

According to the Table it is clear that among the cases considered the highest number of coincidences (five coincidences) have the sixth and seventh series.

4. Conclusions

The program that allows to identify hidden sequence in large data set was developed. This article explains into detail basic principles of search algorithm applicable to the sequences that are based on equation (1).

Application of the program showed sufficient accuracy to identify the hidden sequences, which made it possible to predict the location of undetected spikes in the series.

Analysis of hidden sequences identification

Series Number	Value	Bifurcation point number in the row									
		1	2	3	4	5	6	7	8	9	10
3	NBT, cycl.	1830	8133	17147	24896	29999	32930	34502	35315	35729	35938
	NB, cycl.	—	8000	—	25000	—	33000	34500	—	—	—
	error, %	—	1,64	—	-0,42	—	-0,21	0,01	—	—	—
4	NBT, cycl.	1890	8400	17709	25712	30983	34010	35633	36473	36901	37116
	NB, cycl.	—	8750	—	25500	31000	34000	—	—	—	—
	error, %	—	-4,17	—	0,83	-0,06	0,03	—	—	—	—
5	NBT, cycl.	2020	8978	18927	27481	33114	36349	38084	38982	39439	39669
	NB, cycl.	—	8750	—	27500	33000	—	—	39000	—	—
	error, %	—	2,54	—	-0,07	0,34	—	—	-0,05	—	—
6	NBT, cycl.	2070	9200	19395	28161	33933	37249	39027	39947	40415	40651
	NB, cycl.	—	8750	19500	28000	34000	—	39000	—	—	—
	error, %	—	4,89	-0,54	0,57	-0,20	—	0,07	—	—	—
7	NBT, cycl.	2080	9244	19489	28297	34097	37429	39215	40140	40610	40848
	NB, cycl.	—	8750	19500	28500	34000	37500	—	—	—	—
	error, %	—	5,35	-0,06	-0,72	0,29	-0,19	—	—	—	—

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Описано метод і загальний алгоритм програми для пошуку в експериментальних даних серій, які відповідають заданому рекурентному співвідношенню. Запропоновано пошуково-аналітичну модель, відмінну від існуючих моделей пошуку.

Ключові слова: довірчий інтервал; пошукова модель; рекурентне співвідношення.

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Описаны метод и общий алгоритм программы для поиска в экспериментальных данных серий, соответствующих заданному рекуррентному соотношению. Предложена поисково-аналитическая модель, отличающаясяя от существующих моделей поиска.

Ключевые слова: доверительный интервал; поисковая модель; рекуррентное соотношение.

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