ACCELERATED TESTING OF AGRICULTURAL MACHINERY WITH VARIABLE AMPLITUDE LOADING

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The paper presents the synthetizing algorithm for an accelerated testing program within laboratory of the MAS65 deep soil loosening machine resistance structure, based on real loads at which it is subjected. We determined the real stress for the MAS65 deep soil loosening machine working organ, through measurements performed in the field. By applying an original counting algorithm on the real signal and synthesizing a blocks testing signal from those cycles, we obtained the accelerated testing program within laboratory.

Keywords: peak counting, stress spectrum, accelerated testing.

1. Introduction

The importance of mechanical testing of machines, gears and industrial components, results from the fact that the different types of tests, performed as an integrating part of the research-development and prototyping processes of these different equipment, contribute in a decisive way to obtaining reliable and well designed products.

Accelerated tests represent a way to hasten the information on product behavior in conditions of economic efficiency [1,2,3]. Acceleration of functioning conditions, in terms of “testing time compression” can also be studied according to the number of the cycles to failure. As a result, determination of reliability indicators will be performed as a function of the working cycles. These cycles can be counted using standard counting algorithms, from which we remind the most important ones: peak counting, peak to peak, range-pair, rainflow [4]. Then, based on these cycles, one could test in laboratory conditions the same equipment subjected to the same equivalent stress as in real life. In terms of quantitative tests, in order to accelerate them, there are usual ways to do that, such as usage rate acceleration and/or overstress acceleration by intensifying the load (or loads) over the normal limits, keeping at the same time the breakage mechanism [5,6].

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Experimental researches regarding testing in accelerated regime of agricultural machinery resistance structures, performed by specialists from all over the world, could be superimposed over the classical accelerated models, with some variations. Practically, from the point of view of tests acceleration concept, there are no limits regarding the acceleration mechanism. However we have to keep in mind the good practice guides which stipulate that the accelerated test doesn't have to cause unnatural failures in order to achieve its goal, which could be represented by life time assessment, failure modes and breakage point identification or structural integrity validation [1]. Accelerated testing can be approached either in the time domain or in frequency domain for mechanical excitations performed on the resistance chassis [7].

Through the currently used methods for test acceleration, we remind the acceleration of the usage rate [8], mission profiling and test synthesis [9], accelerated durability tests in the frequency domain [10], method of testing with random loads [11].

The paper proposes a numerical method for accelerated test by block testing [7], using a peak counting algorithm and a mathematical formulation for a sweep sequence made up from sinus signals using the same number of cycles as the original signal. Hence, we performed strain measurements on the excitation point of the resistance structure of MAS65 deep soil loosening machine (its working organ), in view of identifying its real stress spectrum. After that, we have applied a peak counting algorithm, thus obtaining the total number of loading cycles and their amplitudes, grouped on bins of equal width [13]. Next we have synthesized a block testing program in accelerated regime for the MAS65 resistance structure in view of assessing its frame resistance.

2. Materiel and method

Cycles counting algorithm

According to [14], in view of life expectancy determination for structures based on damage accumulation, it is necessary to know the loading cycles, which usually have a random variation. Hence there were developed means specific to signal theory, which don't take into consideration the time variable but only the amplitude and sequence of the signal. Following is presented an algorithm for cycles counting of a random loading sequence of finite length based on the peak counting principle showed in [2]. Using this method, each consecutive local absolute peak is counted as a half-cycle, assuming that the other half is a valley.

Given:

$$\{\sigma_i\}_{i=1,\ldots,N_e} \tag{1}$$

the string of samples, usually representing stress, with total number of samples N_e.

The minimum and maximum values of the string (1) are:

$$\sigma_{\min} = \underbrace{\min}_{i=1,\dots N_e} (\{\sigma_i\}_{i=1,\dots N_e}), \sigma_{\max} = \underbrace{\max}_{i=1,\dots N_e} (\{\sigma_i\}_{i=1,\dots N_e}) \qquad (2)$$

and the mean value of the string is:

$$\overline{\sigma} = \frac{\sum_{i=1}^{N_e} \sigma_i}{N_e} \qquad (3)$$

We also introduce the string amplitude by means of formula (presented in [9]):

$$\sigma_a = \frac{\sigma_{\min} - \sigma_{\max}}{2} \qquad (4)$$

Cycles counting will be performed using a procedure which also constructs a histogram of stress distribution in bins of equal width. Thus from the initial signal we subtract the mean value calculated according to (3). Then we construct a partition of the recorded data. Given σ_{max} the maximum value of the string, and n_{int} the number of bins in which we divide the mechanical stress interval [0, σ_{max}], then:

$$\{s_j\}_{j=0,\dots,n_{\text{int}}} \qquad (5)$$

is the string of histogram bins limits, with n_{int} the number of bins.

Then we propose the following counting formula for the cycles found in each bin N_j:

$$N_j = \sum_{i=1}^{N_e-2} \xi_{ij} \qquad (6)$$

in which :

$$\xi_{ij} = \begin{cases} 1, \text{if } s_j \le \sigma_i < s_{j+1} \text{ and } \sigma_{i-1} \le \sigma_i > \sigma_{i+1} \\ 0, \text{in all other cases} \end{cases} \qquad (7)$$

Conversion of random signal, experimentally determined, to a testing program of sine sweep type with precise characteristics

The next proposed algorithm refers to the selection, from a random signal experimentally obtained, of some sinusoidal signals (with constant frequency and amplitude), which produce the same effect on the structure as the original one. Within laboratory we chose to excite the structure using a known force applied to the working organ of the machine.

According to relation (6) we have determined the number of cycles contained within a real signal. We accept the notion of cycle in terms of stress reversals and not as periodic signal. Next we determine a histogram of the cycles, each cycle being framed within an interval of tensions. Thus we can clearly put into evidence the number of cycles which overpass some reference limits in tension, characteristic to the materiel such as yield point or fatigue limit. The total number of cycles identified with relations (6) and (7), is:

$$N_c = \sum_{j=1}^{n_{\text{int}}} Nj \tag{8}$$

Next we define the reference amplitudes for each bin of the histogram, in view of further defining the equivalent sine signals:

$$a_j = \frac{s_j + s_{j-1}}{2} \tag{9}$$

The frequency of the same cycles category (contained in the same bin of the histogram) is defined by:

$$\nu_j = \frac{N_j}{\max(t) - \min(t)} \tag{10}$$

in which :

$$\{t_i\}_{i=1,\dots,N_e} \tag{11}$$

is the value of time for string defined by equation (1).

Then we define the periods of time signals corresponding to the created bins:

$$T_j = \begin{cases} \dfrac{1}{\nu_j}, \text{if } \nu_j > 0 \\ 0, \text{if } \nu_j \le 0 \end{cases} \tag{12}$$

Now we can define a sine signal which will act on segments with amplitudes given by (9) and frequencies given by (10). These sine signals will be applied as sine sweeps [15], in time intervals of which limits are established by the relation:

$$\tau_j = \tau_{j-1} + N_{j-1} T_{j-1},\ j = 1,\dots,n_{\text{int}},\ \tau_0 = 0 \tag{13}$$

In these conditions we define the signal composed of blocks which contain the same damage as the original signal:

$$\Psi(t) = \sum_{j=1}^{n_{\text{int}}} a_j \sin(2\pi \nu_j t)\chi_j + \overline{\sigma} \tag{14}$$

in which *t* is the time variable of the signal (1) decomposed as in relation (13) and χ_j is given by relation (15).

$$\chi_j = \begin{cases} 1, \text{if } \tau_{j-1} < \text{t} \le \tau_j \\ 0, \text{in all other cases} \end{cases} \tag{15}$$

Calculation of test sequence for tests in accelerated regime

Accelerated tests are defined in the reliability domain as tests meant to shorten the test duration through various means: bigger load amplitudes, faster test frequencies, subjection to shocks, etc. The reasons why a test should be accelerated are mainly because of the lesser testing costs and the chance to obtain the required results in real time.

The accelerated test will be defined by the sine sweep described by equation (14), for which we keep the same amplitude, we multiply the test frequency with a f_a gain, and we divide the time with the same gain factor, in order to keep the sinus argument. We chose f_a gain to be a constant equal to 5, in order to obtain a decent acceleration of test by keeping the same amount of damage and avoiding dynamic amplification.

3. Results and discussions

The structure of MAS65 machine is excited during the field work through its working organ. We mounted a strain gage on this organ in its longitudinal direction and we recorded the strain to which it was subjected.

Fig.1. MAS65 deep soil loosening machine, aspects during experiments

In figure 2 we present the time series signal measured on the working organ during the field work, recorded as mechanical stress (by multiplying the measured strain in the strain gage's direction with the Young modulus of the structure's materiel, $E=2.1 \cdot 10^{11}$Pa), in hypothesis that the loading was performed in the elastic domain and that we performed the measurement on the principal stress direction. This time series signal was recorded for more than 150 seconds, including a dead time period (when the tractor was static), and two transitory regimes, one representing the accelerating startup of the tractor in aggregate with the MAS 65 deep soil loosening machine and the other one representing the stop of the same aggregate. Also the signal contains a period in which the aggregate was actually working the soil on a field length of 200 meters, with a working width of 1.5 meters, meaning a worked surface of 300 square meters. Taking into consideration that per season this type of implement is supposed to work around 150 hectares, one should work the same surface multiplied by 5000 times in the same working conditions. This was an assumption that we accepted when we were preparing the next phase of the test signal generation.

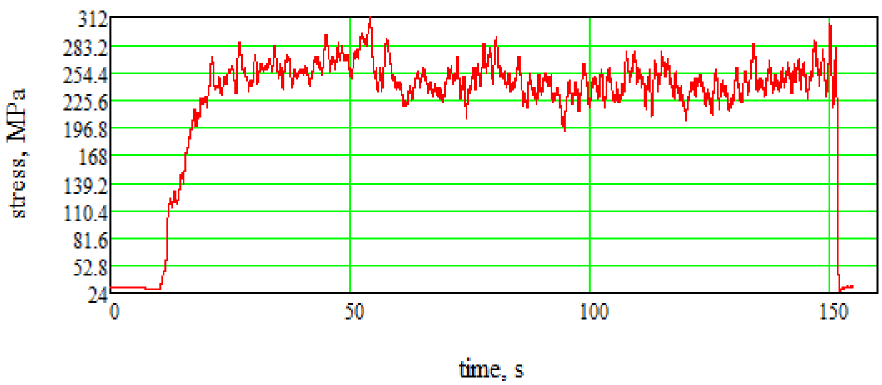

Fig. 2. Original time series obtained in the field

From the original signal we extracted the data contained in the time interval [30, 145] in seconds, thus eliminating the transitory regimes represented by the starting, respectively stopping the equipment, assuming that their influence on the structure's resistance is negligible. We calculated the mean value ($\overline{\sigma}$) and the amplitude value (σ_a) of the new created signal, obtaining the value of 247.58 MPa, respectively 58.9 MPa. The mean value was subtracted from the new signal values, obtaining the broad band variable amplitudes centered in zero, with a time evolution presented in Fig. 3.

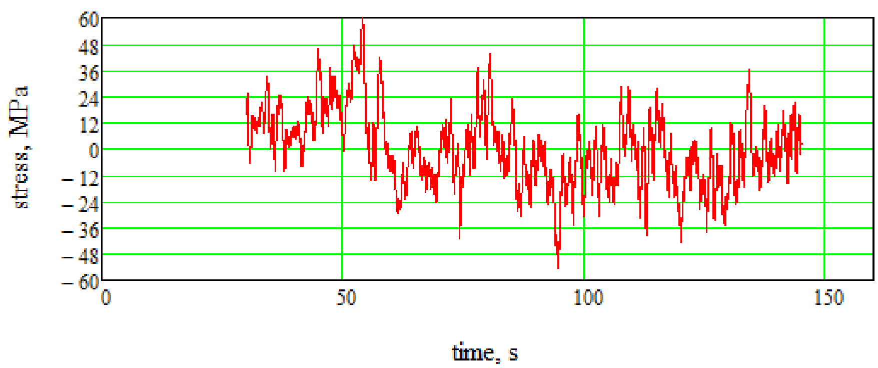

Fig. 3. Amplitudes string centered in zero

Applying the proposed counting algorithm onto this string, according to (6), (7) and (9), we obtained the data shown in table 1, with a total number of 567 cycles throughout all the observed period of 115 seconds. We chose a number of 12 bins of equal width for which to count the cycles within, based on the fact that we needed to span the entire amplitudes domain without losing information.

Table 1

Characteristics of structure's excitation signal after applying the proposed cycles counting algorithm

Number of bin	Number of cycles	Signal amplitudes a_j (MPa)	Original frequencies ν_j (Hz)	Initial period of bin T_j (sec)
1	135	4.908	14.086	9.58
2	133	9.817	13.877	9.58
3	91	14.725	9.495	9.58
4	71	19.633	7.408	9.58
5	58	24.542	6.052	9.58
6	31	29.45	3.235	9.58
7	15	34.358	1.565	9.58
8	11	39.267	1.148	9.58
9	12	44.175	1.252	9.58
10	5	49.083	0.522	9.58
11	2	53.992	0.209	9.58
12	3	58.9	0.313	9.58

In order to accelerate the tests we applied the gain factor f_a and we obtained the accelerated testing frequencies presented in table 2, maintaining the same number of stress cycles on bins but modifying their time duration.

Table 2

Characteristics of structure's excitation signal after applying the proposed acceleration factor

Number of bin	Number of cycles	Signal amplitudes a_j (MPa)	Testing frequency ν' (Hz)	Accelerated period of bin T_j' (sec)
1	135	4.908	70.429	1.916
2	133	9.817	69.385	1.916
3	91	14.725	47.475	1.916
4	71	19.633	37.040	1.916
5	58	24.542	30.260	1.916

Number of bin	Number of cycles	Signal amplitudes a_j (MPa)	Testing frequency ν' (Hz)	Accelerated period of bin T_j' (sec)
6	31	29.45	16.175	1.916
7	15	34.358	7.8250	1.916
8	11	39.267	5.740	1.916
9	12	44.175	6.260	1.916
10	5	49.083	2.610	1.916
11	2	53.992	1.0450	1.916
12	3	58.9	1.5650	1.916

Adding the new values for accelerated periods of bins from the last column of table 2, we obtain the value of 22.992 seconds, this representing the time duration of the accelerated test. In figure 4 we present the sine sweep obtained for the accelerated test program.

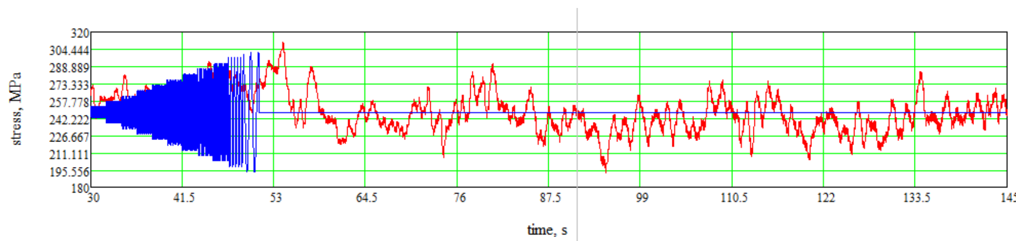

Fig. 4. Accelerated test program - sine sweep
(red - original signal, blue – accelerated sine sweep testing program)

4. Conclusions

In order to perform resistance tests for agricultural machinery in accelerated regime one could identify the stress spectrum in exploitation, make a numerical evaluation of the stress cycles and synthetize a simplified test program of sine form which is easy to count in real time and to apply with conventional testing means. This formulation respects the Gasser's eight blocks testing program for variable amplitude loading principle, with the remark that it is proposed for entire resistance structures of agricultural machinery. We have to keep in mind the assumptions made within the article that the loads are performed in the elastic domain and we only account for the working regime (and not the transportation or transitory regimes).

The deep soil loosening machine MAS65 was tested in real exploitation conditions, thus obtaining its real stress spectrum. By applying the algorithms of counting and test signal generation for accelerated testing we obtained an acceleration factor of 5 in laboratory conditions. Thus, we could proportionally reduce the testing costs in terms of energy consumption.

To reproduce the same amount of damage sustained by the structure during an entire working season, one should repeat this testing sequence 5000 times. By reproducing short duration testing blocks accounting for small worked surfaces, we minimized the sequence effect on the entire working life, giving this way to our newly created test program a Gaussian character.

The proposed method is applicable to any type of agricultural machinery, in hypothesis that one could record real stress in field conditions for the equipment's excitation points. The number of bins as also the acceleration factor could be variable depending on the stress mean and amplitude values.

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