ON THE REAL LOADING MODELING OF THE MECHANICAL SYSTEMS

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Abstract. *The real loading is generally constituted only by the outside forces and torques acting on a system, neglecting other influences. An important problem is the including the aleatory real loading in the strength and reliability estimation. The analysis of the actual state of researches in field promotes an interesting observation: there are not proposed even clear methods and principles in literature regarding the establishment of the model of real loading; these are presented relatively vague omitting essential details for their applying. The strength calculation is based by the correction of the nominal load through factors including the exterior influences. Papers published in Romania in the field of real modeling are also mentioned. Considerations on real loading in the strength and reliability estimation for specific models are presented. There are two models of real loading much used that are discussed in the paper: loading spectra and loading sequences. Final conclusions emphasize the main points of the paper. In this way, the paper offers an up-to-date image on the real loading modeling of the mechanical systems and the new problems that could be focused in future research started at the University POLITEHNICA of Bucharest.*

Keywords: flexion torque, strength calculation, matrix

1. Introduction. Importance and relevance of scientific research field. State of the art

The real loading is generally constituted by outside forces and torques acting on a system, neglecting other factors. It is variable in time (fig. 1) generally in a random way, in the sense that its values cannot be exactly determined over time. It is determined by the working processes or by the surrounding environment, such as wind blasts in the case of airplane, road waves in the case of the motor vehicle etc. The random variation of the real loading is characteristic for numerous functional working fields, for example: aviation, automotive, drilling platforms, wind turbines, reversible acting systems for mills etc. (Buxbaum et al, 1992 [2]; Schütz, Klätschke, Heuler, 1994 [25]).

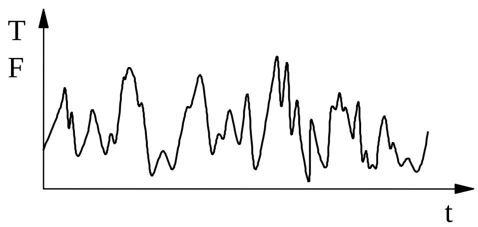


Fig. 1. Measured (random) variation of the real loading
t – time; T – torque; F – force.

Importance and relevance of scientific research field. The consideration of the real loading in the strength calculation and reliability estimation gives the following distinct advantages: 1. the more accurate strength calculation of mechanical components (fatigue calculation); 2. the estimation of the working life and of the provisional reliability of a mechanical system, which is an aspect of interest specially for those systems having a high reliability (the fields of the air frames, automotives etc.); 3. the reduction of the system dimensions, with advantages in terms of: a) lower price; b) reduction of energy use.

State of the art. The inclusion of the random real loading in the strength calculation and reliability estimation of a mechanical system could be made if there are clear experimental data on loading in time and under given working conditions. A very interesting research problem is to do this inclusion in the absence of reliable and adequate experimental data. These aspects are covered only by disparate research reports. Thus, the literature offers references to the loading processes as (Buxbaum et al, 1992 [2]): stress on the automotive back axle; stress on the axle pin of automotive wheel; driving torque al mill; flexion torque of the automotive axle neck; acceleration of the centre of gravity of the aircraft; pressure from pipe tube etc.

But the literature does not give well defined methods and principles to consider the real loading in the strength analysis or the processing and interpretation of the results of the processing of the loading models (Buck, 1973 [1]; Günther et al, 1973 [7]; Haibach, 1989 [8]; Heinisch, 1985 [9], 1986 a [10] and 1986 b [11]; Schütz Klätschke, Heuler, 1994 [25]; Seifried, Müller, 1982 [26]; NF A03-406 [23]; DIN 45667 [5]). Thus:

1. the effect of the measurement time on the precision of the real loading model is not clearly presented;
2. methodologies have not been formulated to separately record real loading during different operating steps, to produce real loading models for each step, to combine them into a global model and to compare the model obtained in this way with that obtained directly;
3. a comparative analysis of different counting-classification procedures is not carried out;
4. there is an insufficient number of studies linked to the extrapolation to the whole life of the different types of loading models.

The present strength analysis is based as a rule on the use of the so called nominal loads corrected by factors including external influences (of the motor machine and of driving system) (ISO 6336-1:2006 [12] gives the application factor for gears).

In Romania, interesting considerations about the use of the real loading were developed by Cioclov (1975) [4], Buzdugan & Blumenfeld (1979) [3] and Rusu & Teodeorescu (1992) [24]. At the University POLITEHNICA of Bucharest a large team carried out research (mentioned partially in the list of references) on models for real loading. These papers have applications to gears (Dobre, Radulescu Mirica, 1994 [6]; Mirica, Dobre, Cananau, 2000 [19]; Mirica, Dobre, 2000 [14], 2002 [15], 2005 [16], 2006 [17]), other machine elements (Mirica, Dobre, Dascaliuc, Ignat, 2006 [20]; Mirică, Dobre, Miloiu, Dascaliuc, 2006 [21]) or mechanical systems (Mirica, Dobre, 2007 [18]; Mirica, Dobre, Itu, Dumitrescu, 2009 [22]).

2. Models of real loading

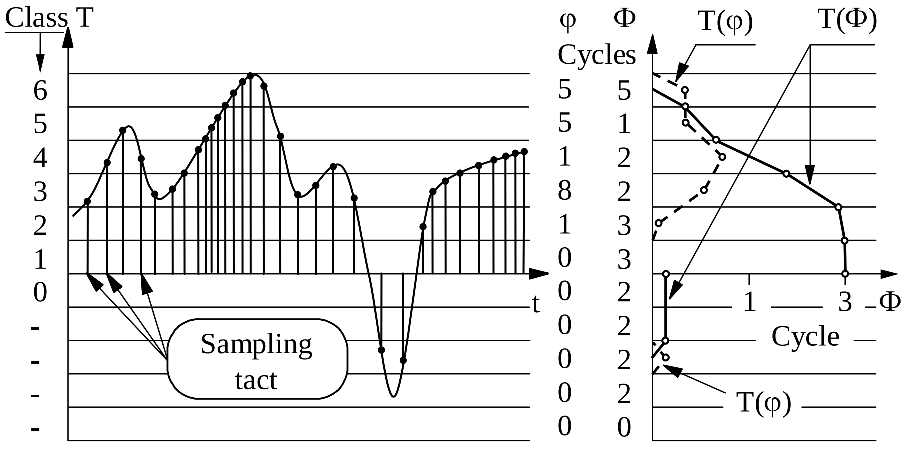
Real loading in strength calculation and reliability estimation is considered for specific models. There are two models of real loading frequently used: 1. loading spectra; 2. loading sequences.

Loading spectrum. An example of the significance of this concept is given further down. The real loading (fig. 1) is replaced, using a procedure for counting – classification (there are many such procedures, of which one is given succinctly in fig. 2, a, b), by so-called **loading spectrum** (fig. 2, c).

This loading spectrum represents the amplitude, $M_t(\Phi)$ of the system loading as a function of the cumulated frequency of occurrence Φ (dimensionless or terms of cycles in fig. 2, c). The loading spectrum characteristic for the whole life of the system is obtained from a set of partial spectra (for short measurement times) extrapolated for this duration by a statistical process (Heinisch, 1985 [9]). An example of this spectrum discretized in steps (to make the calculation simpler) is given in fig. 3.

The spectrum shown in this figure represents the loading modulated in amplitude (the torque on a shaft) serving, for example, to establish the modulated force on a wheel tooth in the case of gear transmission etc.

If the loading is not modulated, as in the case of an airplane wing, then the spectrum is described by two curves or two steps delimiting the minimal and maximal values of the loading cycles.



a b c

Fig. 2. Method to count the loading (torque) in classes to establish the loading spectra, Mt (Φ), adequate for the modulated loading
a) Principle of sampling the torque; b) table of results; c) graphical representation of classing result.
t - time; Mt(t) - function of time of the torque; φ - relative frequency of occurrence in classes of the discrete values of torque; Φ - cumulated frequency of occurrence of the same discrete values.

Even though the spectra do not contain information about the succession of the numbered cycles, these represent today the main way to characterize real loading, due to the following advantages:

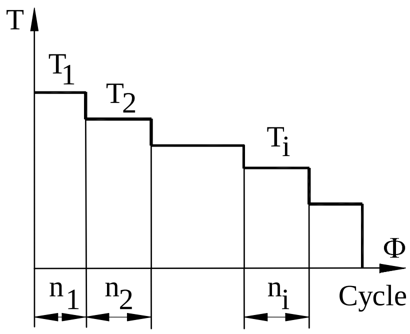


Fig. 3. Loading spectrum discredited in steps

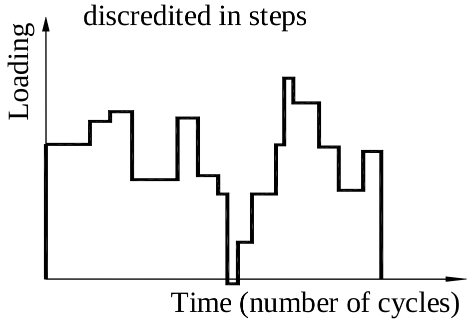


Fig. 4. Loading sequence in steps

1. the spectra are easily determined through general purpose data acquisition equipment configured accordingly;
2. they could be extrapolated to the whole life of the studied system;
3. they could be often approximated by unitary spectra idealized approximately by continuous curves;
4. they permit the transposition of experimental results of “operating strength” (accomplished on the test rig) to other similar systems.

Loading sequence. The second model for replacing time-varying loading is the so called **loading sequence** with the characteristics listed below.

1. The sequence variation form is obtained by the statistical procedure of the time-varying real loading.
2. As in the case of the loading spectrum, this variation of the loading in model (sequence) can represent the modulated loading as in fig. 4 (for example, the torque on a shaft in the case of gear transmissions) on the sequence duration; and if the loading is non-modulated, as in the case of a airplane wing, then the sequence consists of two curves or graphics in steps, delimiting the minimal and maximal

values of the loading cycles.

3. The sequence duration is established in the idea of the repeatability of its cycle by a given number time on the product life, so that this sequence characterizes discretely sufficiently exact the random variable loading of the product under the stress aspect and of its life duration.
4. The are **two types of loading sequences:** bloc-programs and sequences with cycles combined quasi-randomly.
5. **Case of program-block sequences.** The random character of the real loading is simulated by the sequence order of blocks which constitute sequences that need to be repeated a large number of times until a defect appears. The block lengths are determined arbitrarily by keeping the proportion from the spectrum frame and steps with a low frequency of occurrence can be missing from some programs and can be cumulated in others. Consequently, for a given spectrum a number of types of different sequences can be realized through the inclusion (or not) of those blocks of large amplitude and low frequency. Usual variants of ordering the blocks in the frame of loading sequences are given in fig. 5.

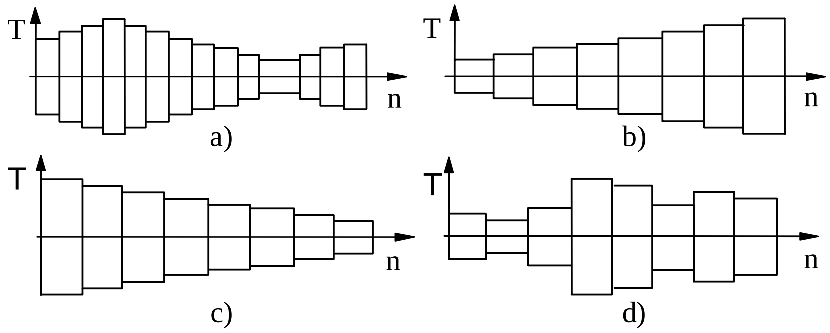


Fig. 5. Loading sequences of torque T, in blocks ordered combined (a), increasing (b), decreasing (c) and random (d), as a function of the number of cycles n (after Haibach, 1989 [8])

6. **Case of quasi-random sequences.** These sequences were developed in the 1970s, when tensile testing machines were perfected. The sequences are based on a matrix of combination of Markov or Rain-flow cycles (NF A03-406, 1993 [23]; Johannesson, Thomas, 2001 [13]). The principle of test (ex-perimental deter-mination) of the Markov matrix is presented in fig. 6. One can see that real loading as a function of time is characterized by a succession of peaks (return points) that are bordered into one of the classes in which the signal variation domain is divided (fig. 6, a). In the matrix from fig. 6, b the transfers from one class to another are counted; on this basis the probabilities of transfer are determined (Haibach, 1989 [8]). The matrix contains information on the number, the maximal and minimal local values of the loading variation and the combination of the cycles. The synthesis of the sequence is realized by the quasi-random generation of a series of picks with the probability of succession in accordance with the one contained in the matrix. Practically a sequence of cycles similar to the one measured is synthesized.

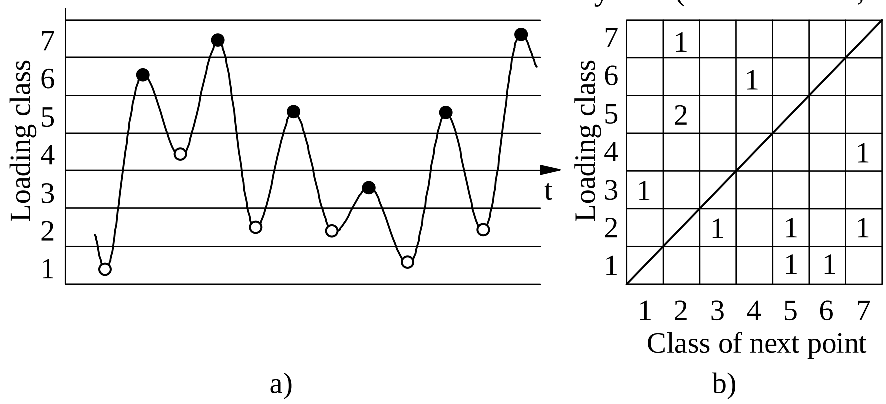


Fig. 6. Method of matrix count - classing (after Buxbaum, 1992 [2])
a) Measured function in time of the loading; b) Markov matrix inscribing results of the transfer count from a class into other. t – time.

3. Conclusions

a) The real loading, which is variable in time, has to be modeled statistically and included in reliability estimation (instead of classical strength calculation), for important advantages.

b) The engineering fields of application of this aspect are large and diverse: aviation, automotive, drilling platforms, wind turbines, reversible acting systems for mills etc.

c) Existing literature does not give well defined methods and principles for the modeling, processing and interpretation of results for real loading and for the consideration of the loading model in calculation.

d) Some contributions to the real modeling process were developed at the University POLITEHNICA of Bucharest.

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