APPLICATION OF VIBROACOUSTIC DIAGNOSTICS IN REMAINING USEFUL LIFE ANALYSIS

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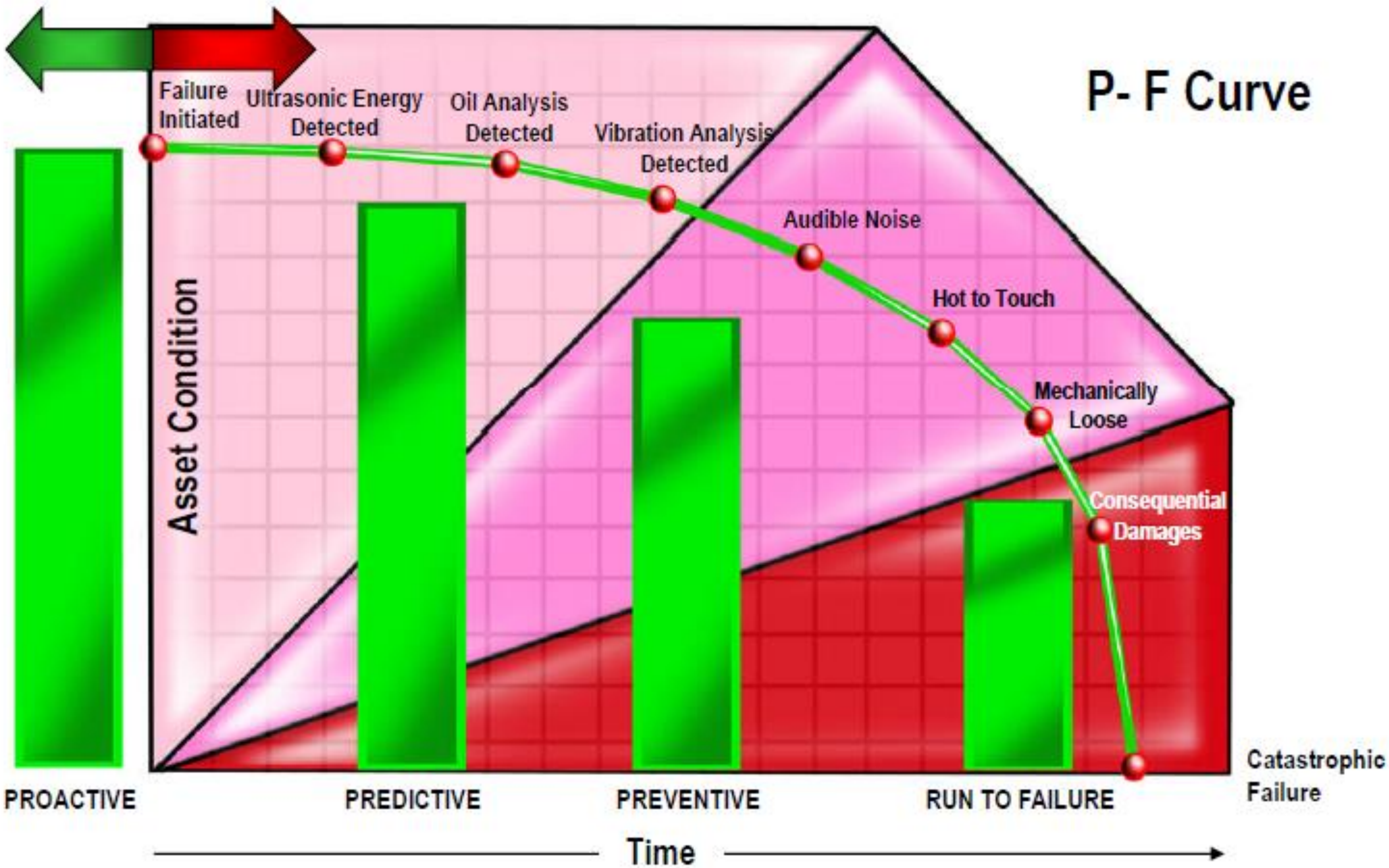
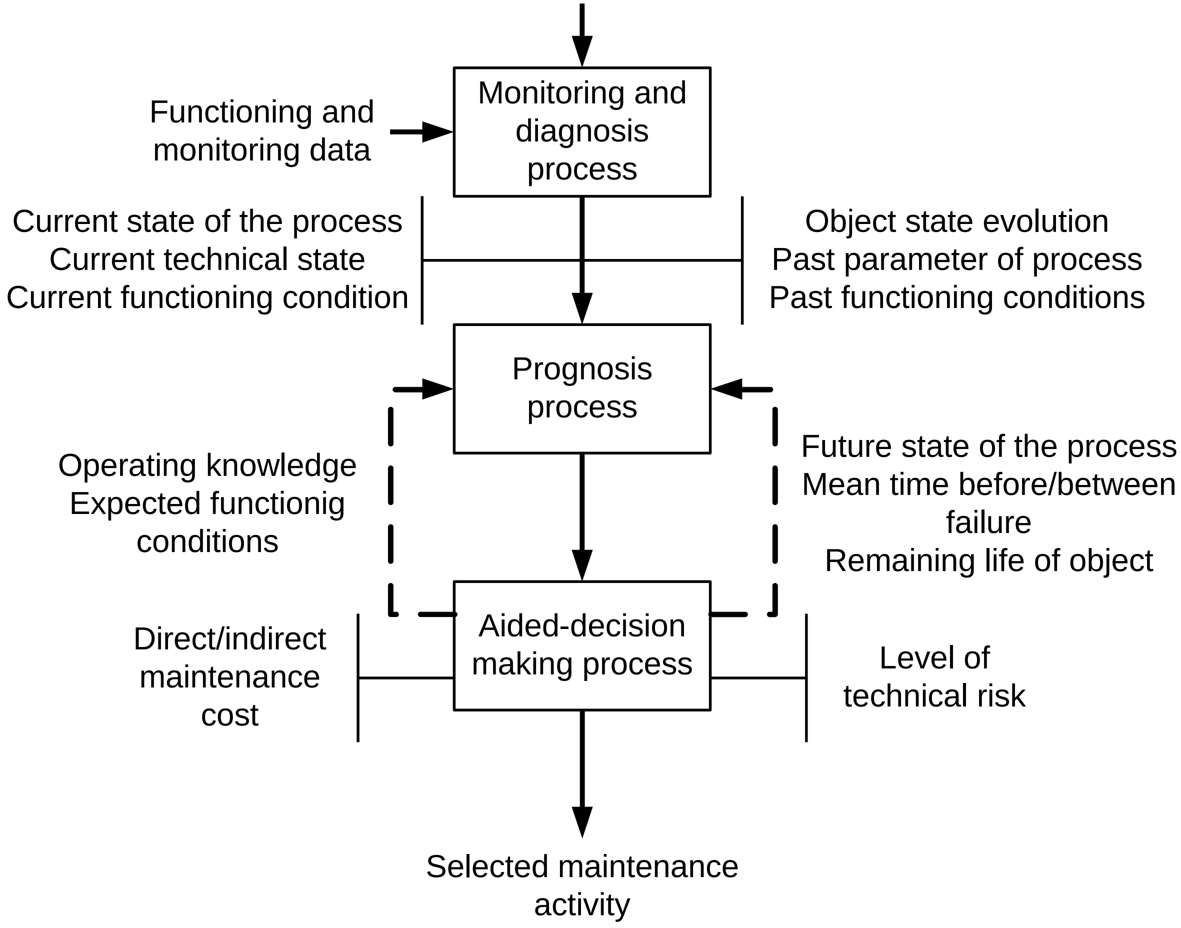
Early Identification of Defects How CBM Works



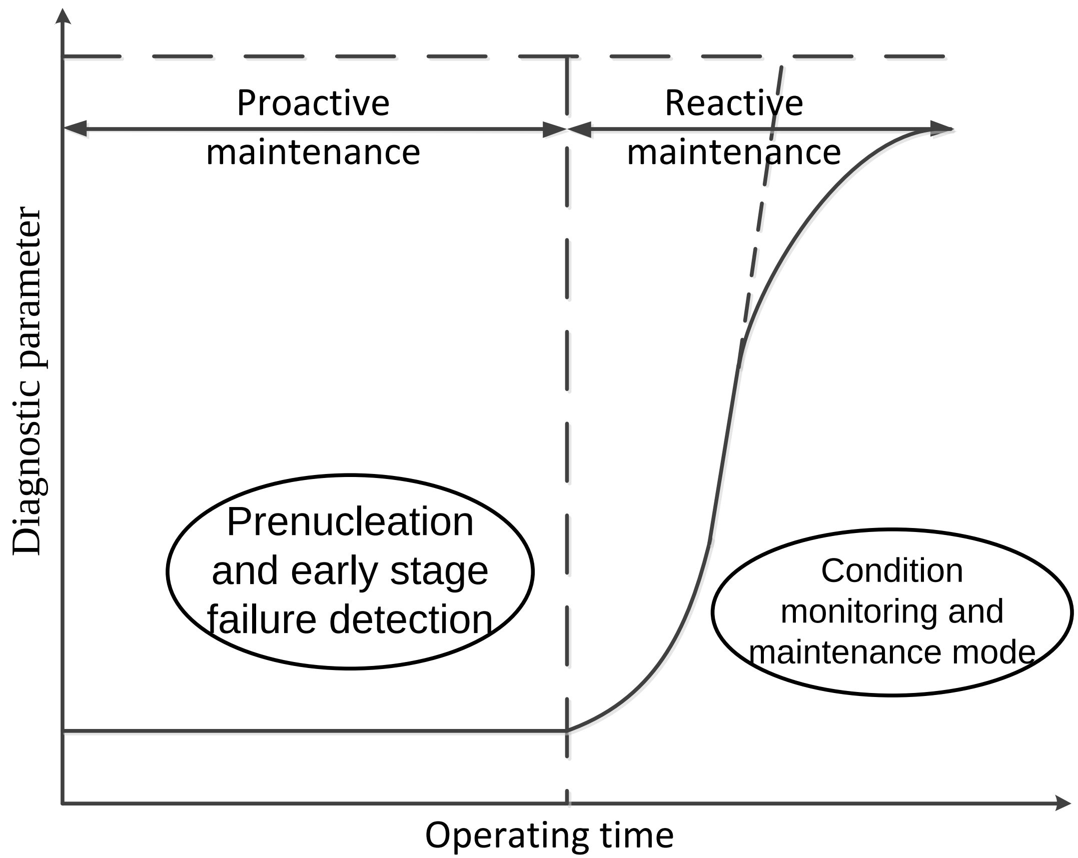
• Proactive maintenance strategy:

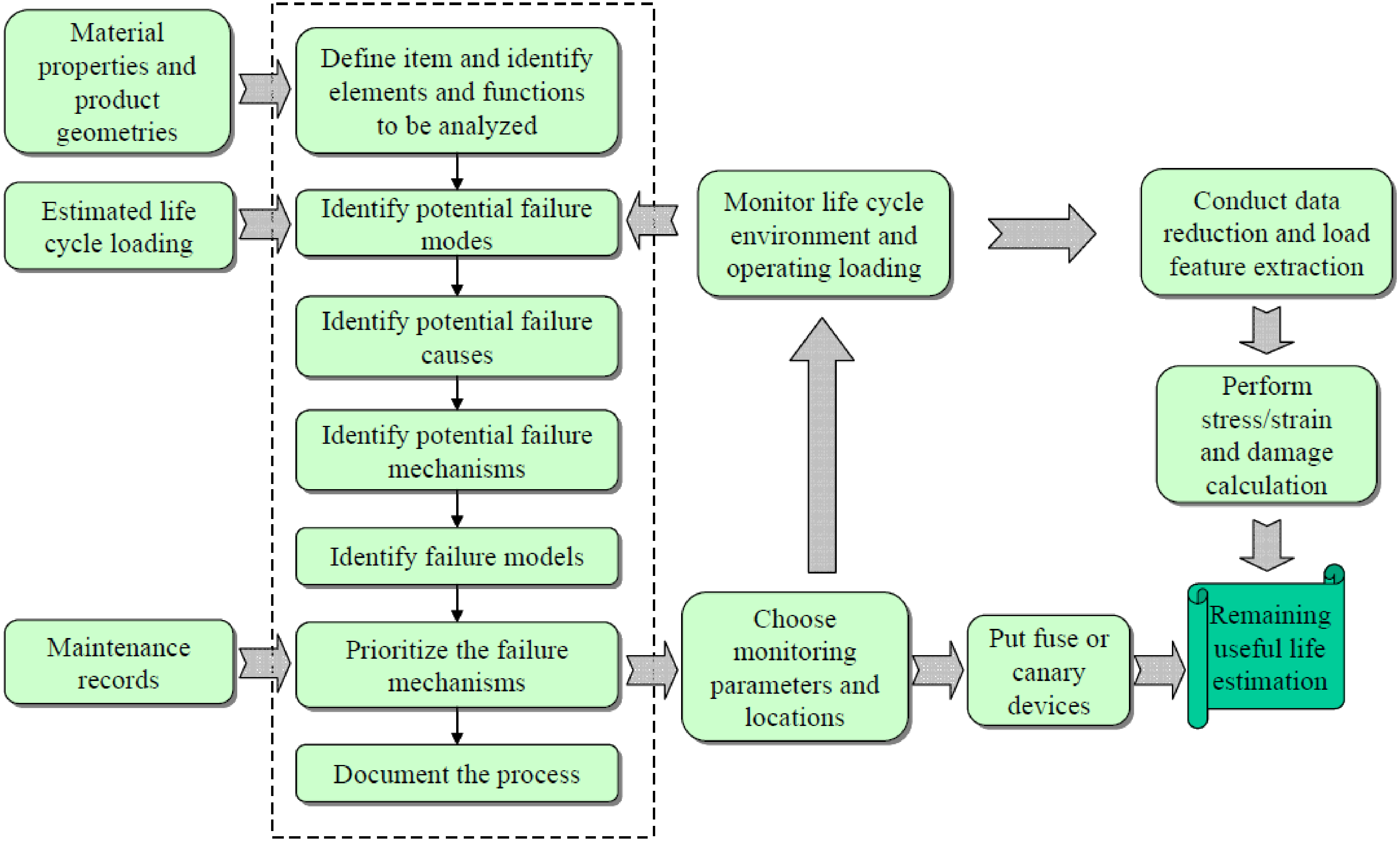
Anticipation action which characterises a proactive maintenance strategy is mainly based on monitoring, diagnosis, prognosis and aided decision-making modules. Among these modules, the prognosis process is often considered while its goal is fundamental for implementing anticipation capabilities.

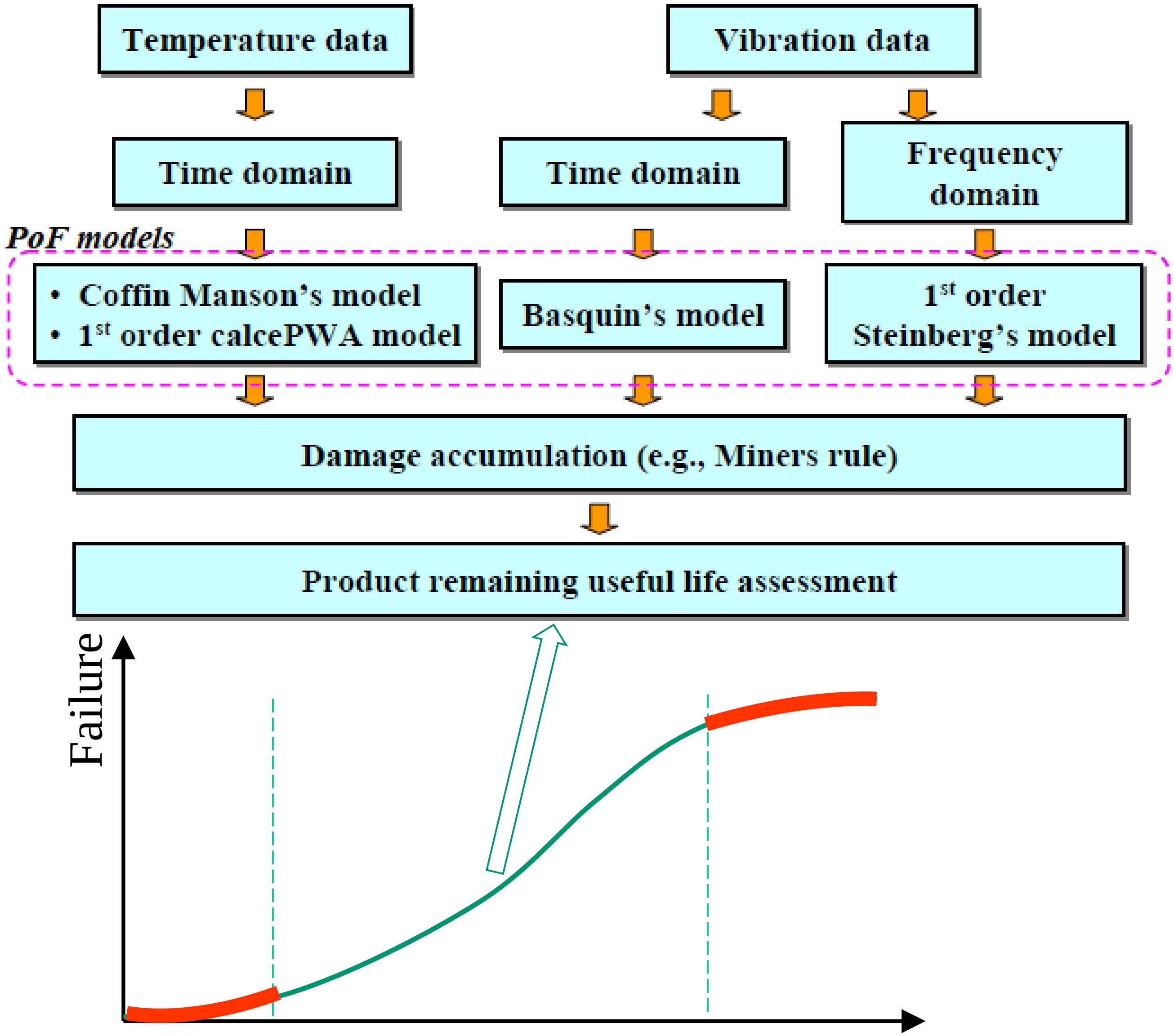
• The prognosis aims at forecasting the future of an item from its present, its past, its degradation laws, and the actions to be considered.



Architecture of the proactive maintenance system


Proactive maintenance
Reactive maintenance
Diagnostic parameter
Prenucleation and early stage failure detection
Condition monitoring and maintenance mode
Operating time


Material properties and product geometries
Estimated life cycle loading
Maintenance records
Define item and identify elements and functions to be analyzed
Identify potential failure modes
Identify potential failure causes
Identify potential failure mechanisms
Identify failure models
Prioritize the failure mechanisms
Document the process
Monitor life cycle environment and operating loading
Conduct data reduction and load feature extraction
Perform stress/strain and damage calculation
Choose monitoring parameters and locations
Put fuse or canary devices
Remaining useful life estimation


Temperature data
Vibration data
Time domain
Time domain
Frequency domain
PoF models
• Coffin Manson's model
• 1st order calcePWA model
Basquin's model
1st order Steinberg's model
Damage accumulation (e.g., Miners rule)
Product remaining useful life assessment
Failure

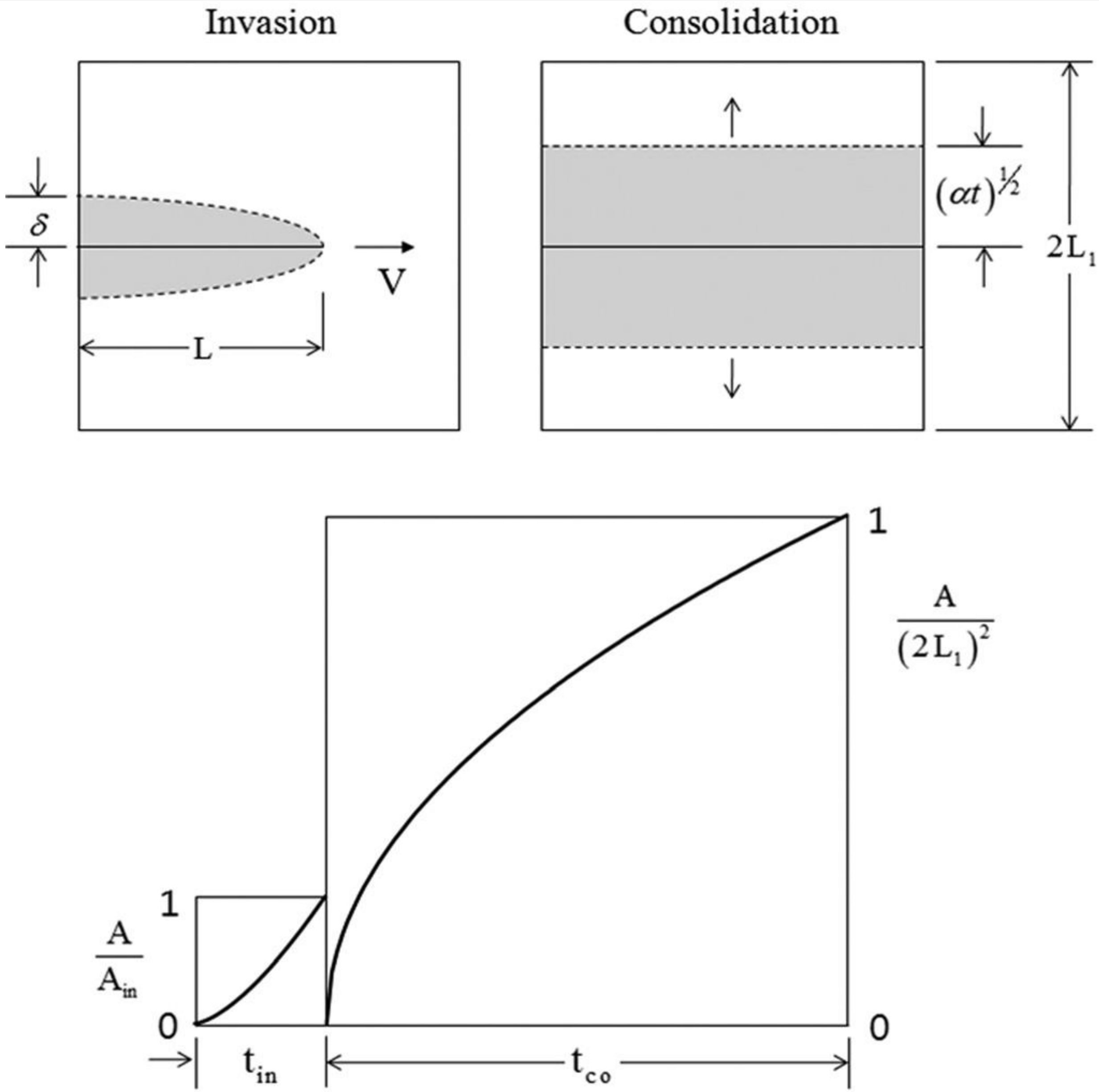
Logistics Function

$$PD = \frac{a}{1 + be^{-ct}}$$

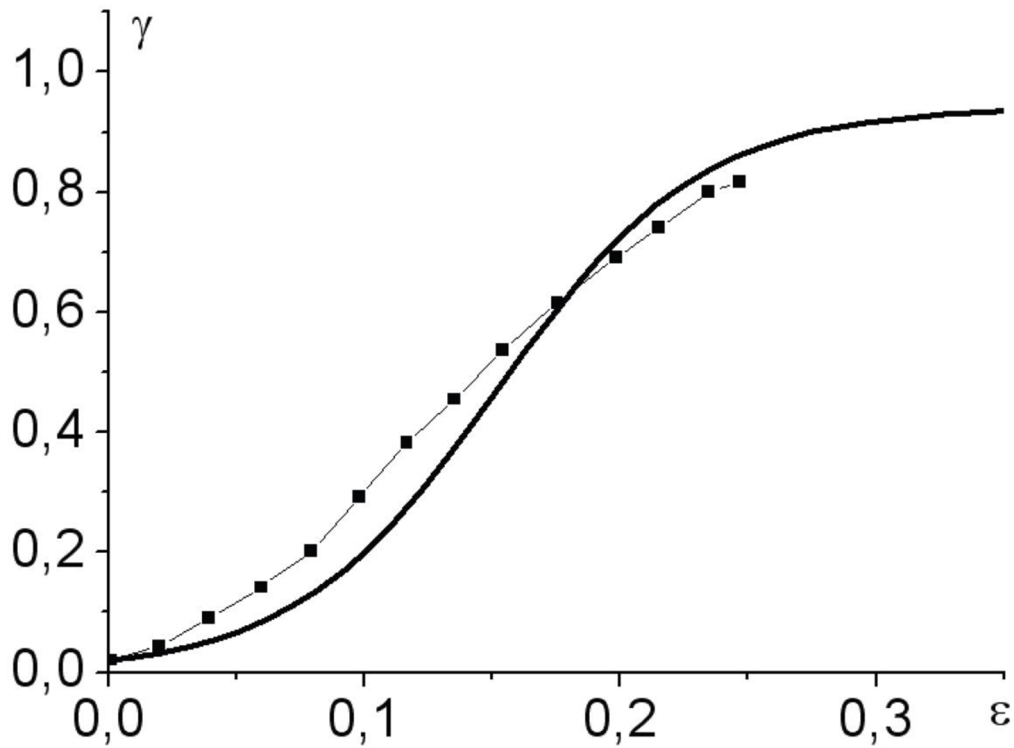
where:

a, b c - constants, $a = a(\sigma)$, $b = b(\sigma)$, $c = c(\sigma)$

t – time



Line-shaped invasion, followed by consolidation by transversal diffusion. The predicted history of the area covered by diffusion reveals the S-shape curve. [A. Bejan, S. Lorente, „The constructal law origin of the logistics S curve" J. Appl. Phys. **110**, 024901 (2011)]



•Arutyunyan A. R., Arutyunyan R. A, The Fatigue Fracture Criterion Based on the Latent Energy Approach, Engineering, 2010, 2, pp 318-321, 2010;

Parameters estimation

$$PD = \frac{a}{1+be^{-ct}} \Rightarrow \frac{dPD}{dt} = PD\frac{c}{a}(a-PD)$$

$$\frac{dPD}{dt}\frac{1}{PD} = c - \frac{c}{a}PD$$

Linear function:

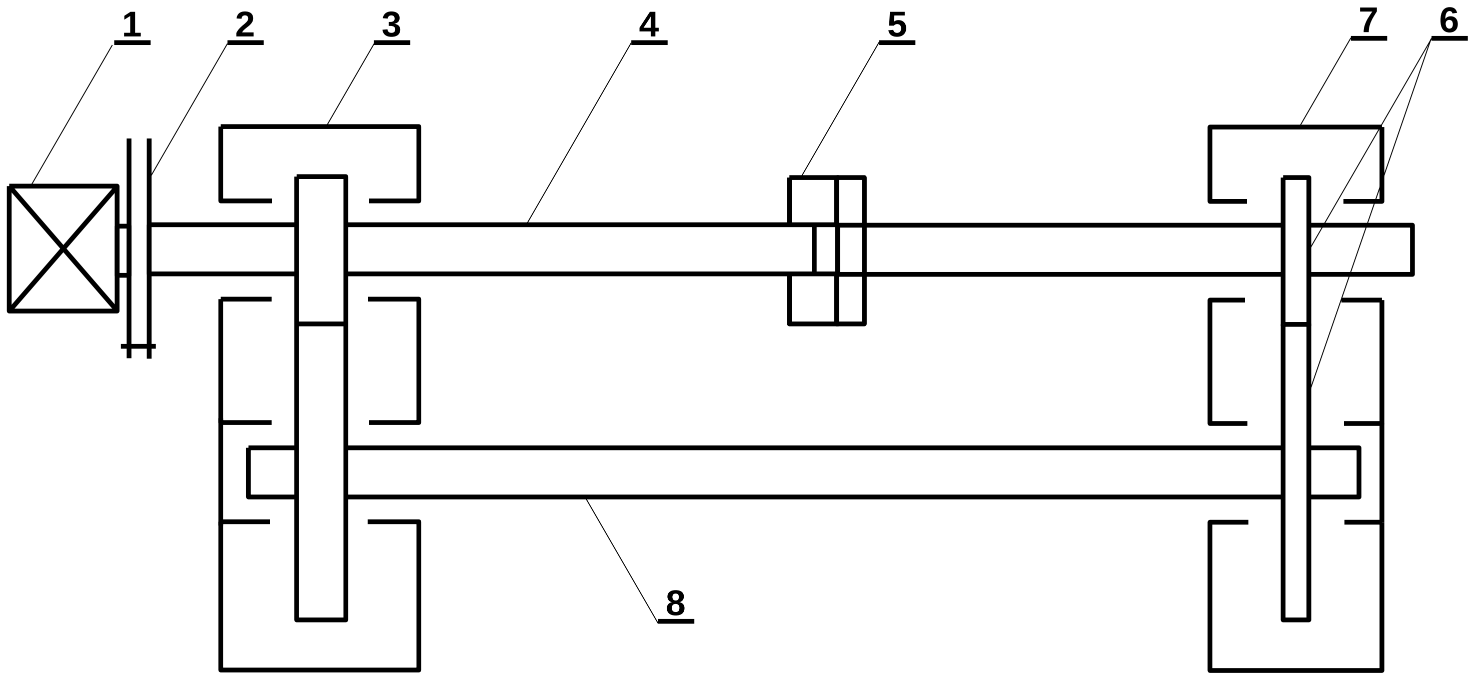
$$y = Ax + B$$

$$A = -\frac{c}{a} \qquad B = c$$

so:

$$a = -\frac{B}{A} \qquad c = B$$

Test-bed diagram

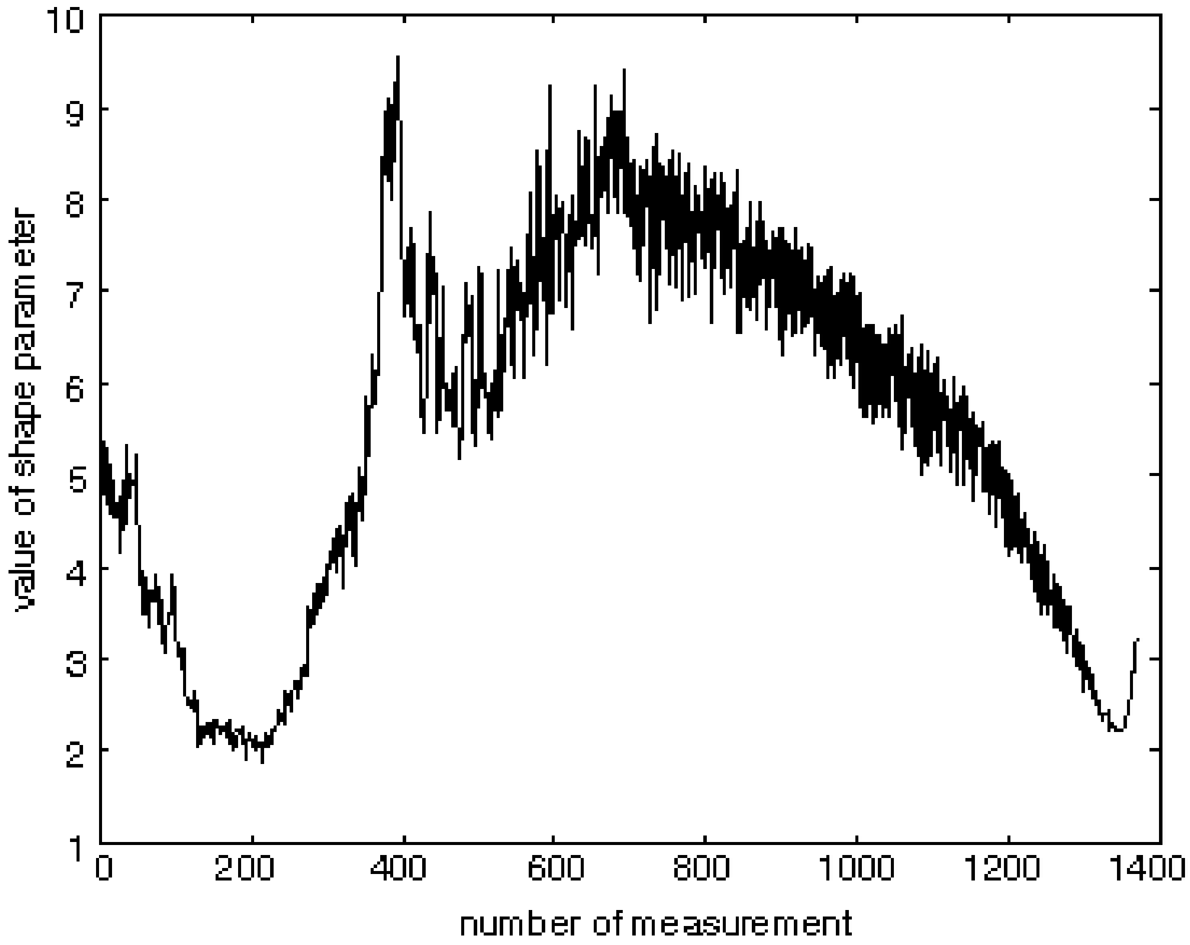


1 — motor, 2 — clutch, 3 — closing gear, 4 — coupling shaft, 5 — prestressed clutch,6 — examined toothed wheels, 7 — examined gear, 8 — shaft

Parameters of the test-bed

- Maximum tensioning torque 1200Nm (or 1500Nm for shafts with bigger torsional rigidity):
- Motor speed: 1460 rpm;
- Gear ratio in both toothed gears: 1.296;
- Module of test specimen wheels and counter-test specimen wheels 4mm;
- Number of teeth in test specimen wheels: 27;
- Number of teeth in counter-test specimen wheels: 35;
- Axle base for wheels: 125 mm.

Toothed wheels made of 20H2N4A carburized steel, hardened to 60 HRC hardness were used for the research.



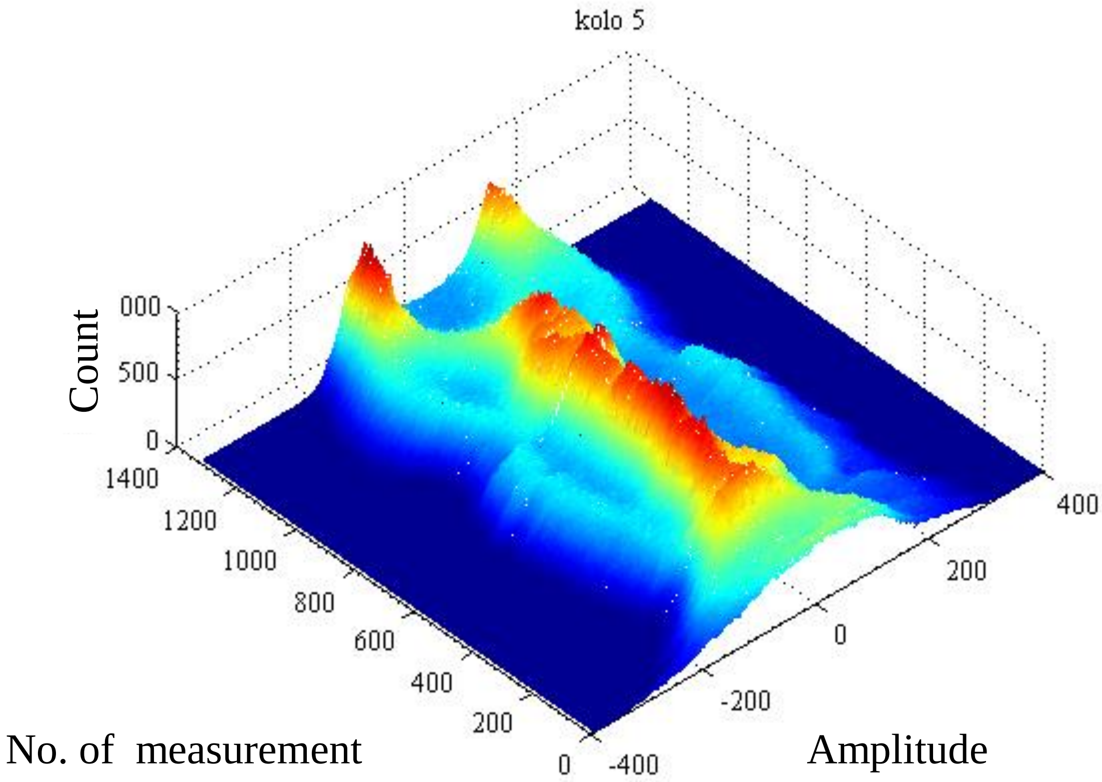
The parameter of shape in function of measurement number of wheel no7.

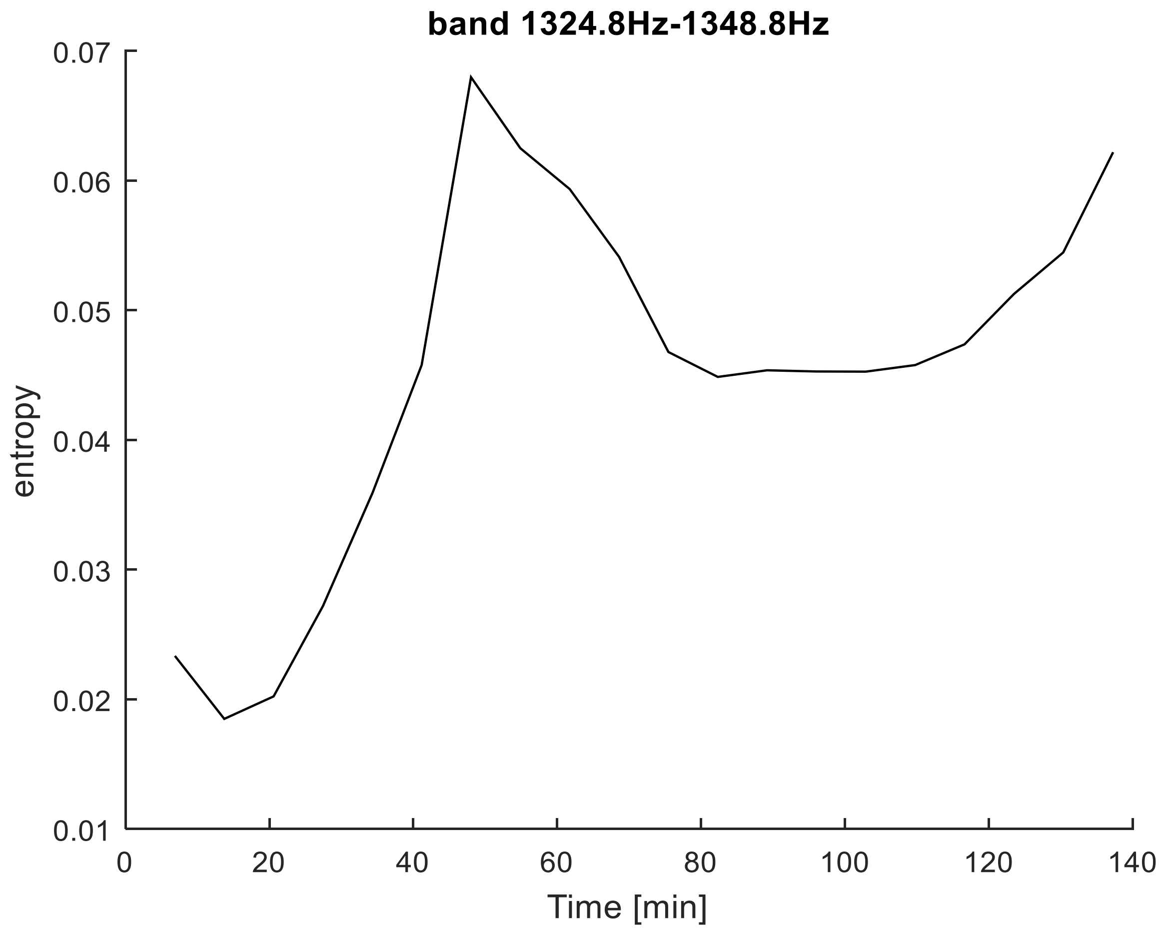
$$H(\zeta) = \sum_{i=1}^{N} p_{si} ln p_{si}$$

$$p_{si} = \frac{\sum_{si} E(\zeta_i)}{\sum_{s} E(\zeta_i)}$$

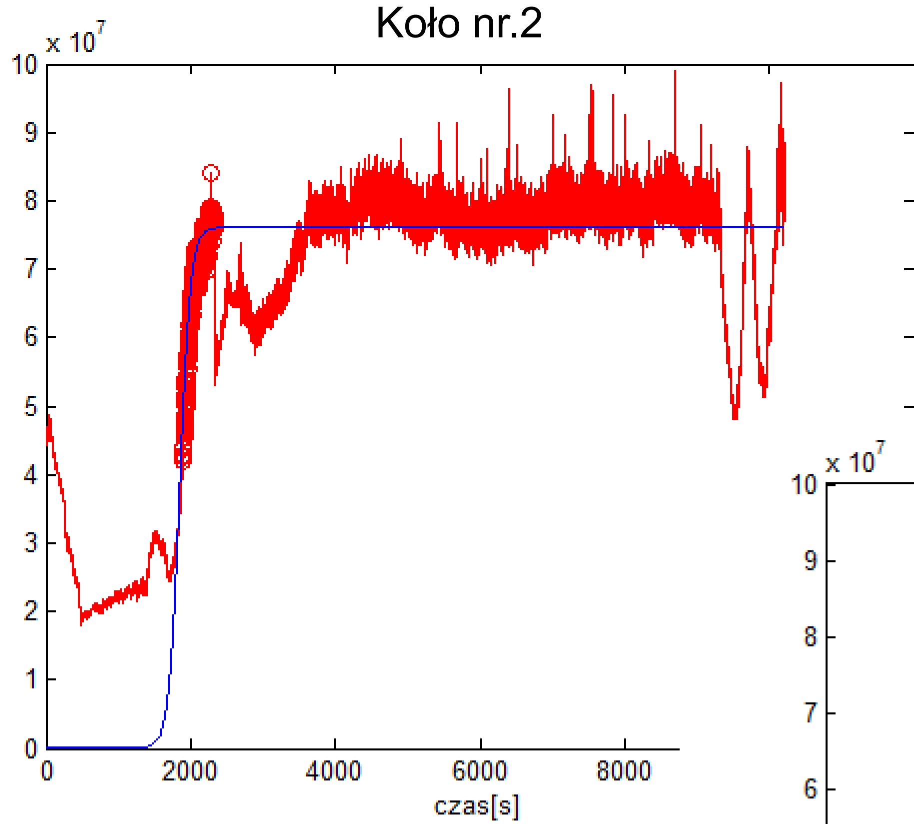
$$p_i = \frac{E_i}{E}$$

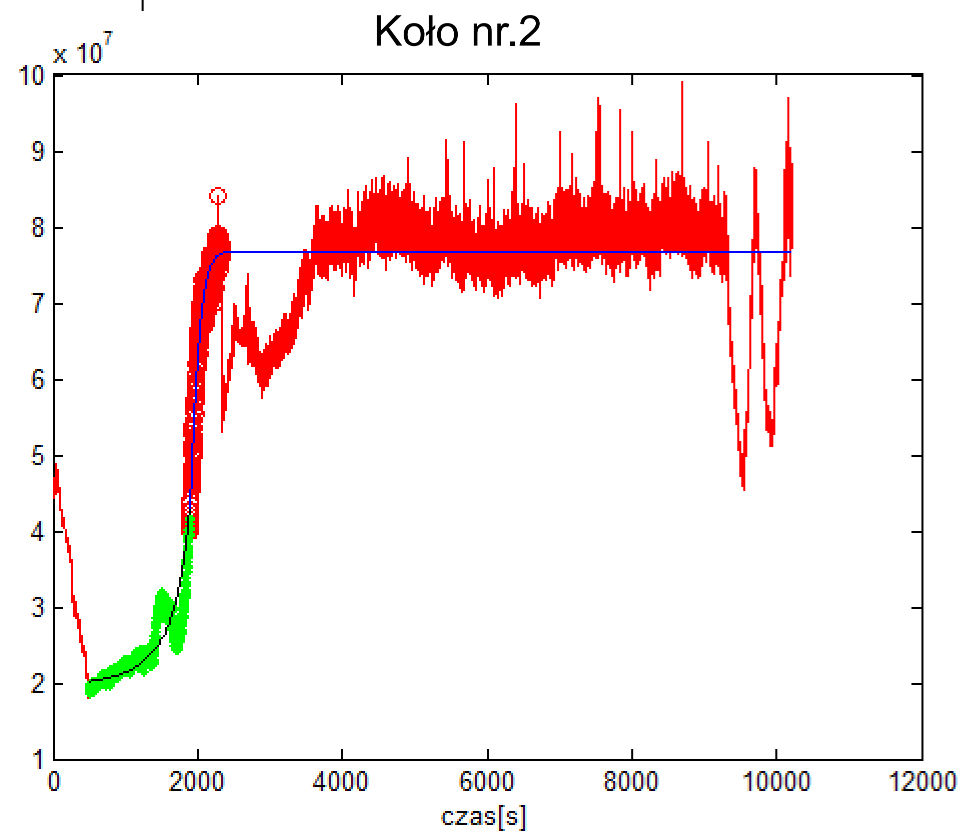
$$H[E] = -\sum_{i=1}^{N} p_i ln p_i$$


kolo 5
Count
000
500
0
1400
1200
1000
800
600
400
200
0
-400
-200
0
200
400
No. of measurement
Amplitude



Shows the change of entropy energy as a function of the duration of the experiment


Koło nr.2
x 10^7
10
9
8
7
6
5
4
3
2
1
0
0
2000
4000
6000
8000
czas[s]


Koło nr.2
x 10^7
10
9
8
7
6
5
4
3
2
1
0
2000
4000
6000
8000
10000
12000
czas[s]

$$PD = \frac{a}{1+be^{-ct}}$$

	cz. I		cz. II	
koło nr.3	b	-4,2E-04	b	2,3E+02
koło nr.7	b	-4,0E-02	b	5,4E+01
koło nr.8	b	-4,0E-02	b	7,8E+01

Bayesian updating method

$$f(a/D) = \frac{f(D/a)\,f(a)}{f(D)} \propto f(D/a)\,f(a)$$

$$f(a/D) = K_B \cdot L[D/a] \cdot f(a)$$

where:

K_B - standardizing constant

L[D/a] - likelihood function

$$L[D/a] = \prod_{i=1}^{n} p(\theta_f / a) \times \prod_{j=1}^{m} [1 - P(\theta_f / a)]$$

where:

n – denotes the set of detected defects

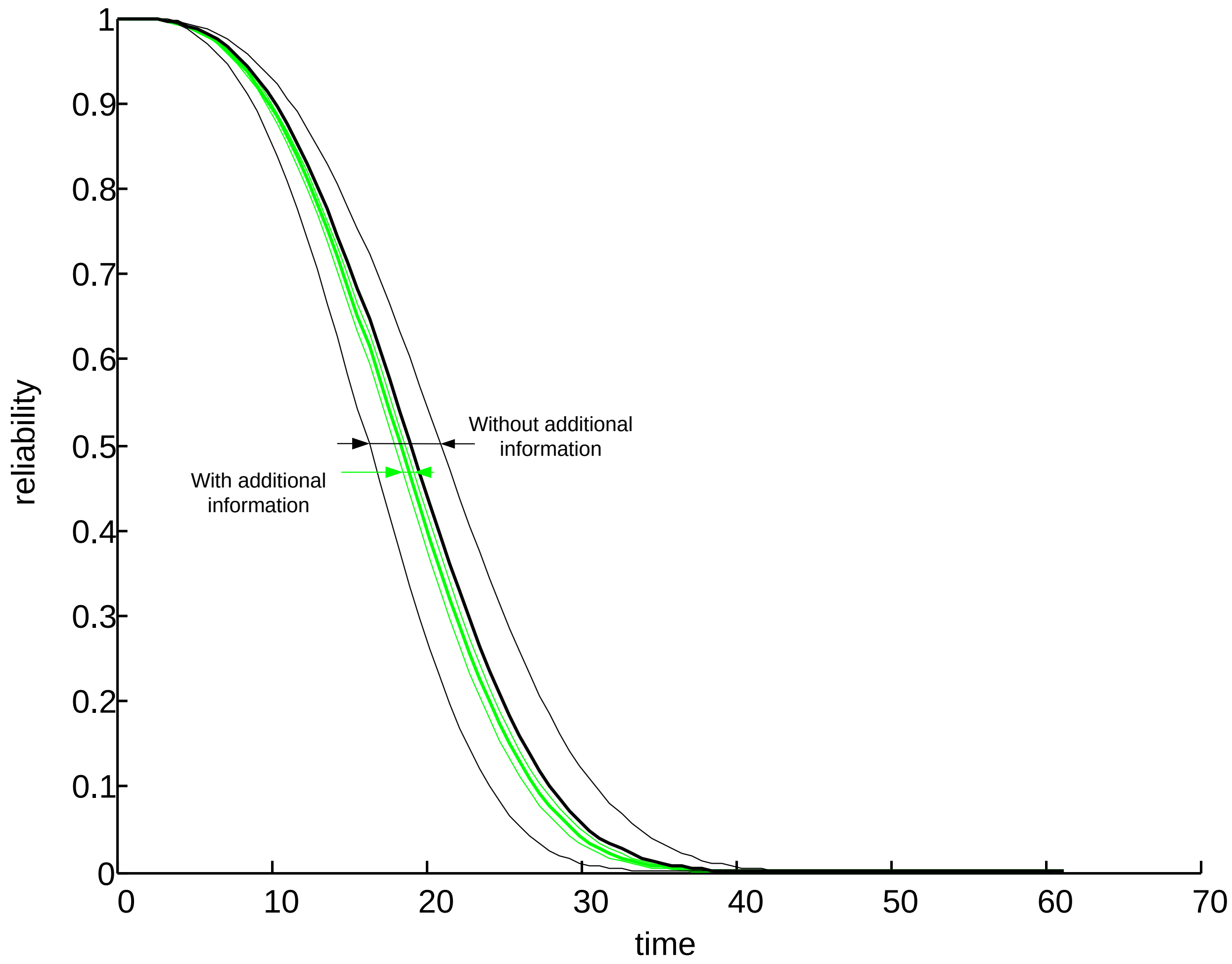
m – denotes the set of events defining non-existence of a defect.

$$f(a) \propto (\det \mathrm{I}(a))^{1/2}$$

where:

$\mathrm{I}(a) = -E\left[\dfrac{\partial^2 \ln f(D/a)}{\partial a^2}\right]$ – is calculated as the matrix of average second derivatives from the credibility function logarithm based on the results of the experiment.

$$f(a/D) \propto L(D/a)(\det \mathrm{I}(a))^{1/2}$$



Reliability function with 90% of confidence bounds.

CONCLUSIONS

The damage parameter defined as the relative changes of energy is introduced. It is shown, that this parameter is governed by the differential equation with the solution in the form of the logistics function, capable to describe different processes leading to saturation.

The method of research presented in the paper enables use of vibroacoustic signals for building the degradation as well as fatigue models, defining the remaining useful life, formulating more reliable diagnoses and forecasts of an object's technical condition. Presented method can be used to test the dynamical output of building structure.

Thank you for your attention