ENERGETIC CHARACTERISTICS OF PRESTRESSED CONCRETE BEAMS DEGRADATION

Henryk KAŹMIERCZAK[1)], Tadeusz PAWŁOWSKI[1)], Jacek KROMULSK[1)], Roman BARCZEWSKI[2)]

[1)] Przemysłowy Instytut Maszyn Rolniczych 60-963 Poznań, ul. Starołęcka 31
tel. 061.8712279, e-mail: kazmhenr@pimr.poznan.pl,
[2)] Politechnika Poznańska Instytut Mechaniki Stosowanej, 60-965 Poznań, ul. Piotrowo 3
tel. 061.6652390 e-mail: roman.barczewski@put.poznan.pl

Summary

This paper presents spatial, energetic characteristics of vibration loads, describing diagnostic conditions of specific mechanical obiect. The method is applied in structural changes in mechanical objects. The beam has been subjected to a cyclic one-sided bending. In particular stages of the structure's cyclic loading the transverse dynamic power has been increased to 2 kN, from 4 to 24 kN. The frequency of cyclic overloading and transverse unloading of the beam oscillated between 0.1- 0.3 Hz. A dynamic effect of the beam's loads was a gradual degradation of its structure. The beam's degradation state, caused by the increase of load, showed the changes of characteristics' maxima frequencies. The decrease of the frequency of the beam's natural vibrations was a result of the decrease of its dynamic rigidity and the changes of the internally dissipated energy. Maxima for high loads characterised the process of cracking and breaking of the beam.

Keywords: degradation state, structural changes, dynamic rigidity, prestressed concrete beam.

OCENA STANU DEGRADACJI BELEK STRUNOBETONOWYCH
ZA POMOCĄ ANALIZY ROZKŁADU MOCY

Streszczenie

W artykule przedstawiono zastosowanie metody analizy rozkładu mocy obciążeń dynamicznych do opisu stanu technicznego obiektu i procesu degradacji obiektu mechanicznego. Metoda stosowana jest w badaniach zmian strukturalnych w obiektach mechanicznych. Belkę struno-betonową poddawano wieloetapowemu cyklicznemu zginaniu jednostronnemu. W poszczególnych etapach cyklicznego obciążania struktury siła dynamiczna poprzeczna była zwiększana o 2 kN, od 4 do 24 kN. Częstotliwość cyklicznego obciążania i odciążania poprzecznego belki zawierała się w granicach 0.1 - 0.3 Hz. Stan degradacji belki, spowodowany wzrostem obciążenia, objawił się zmianami częstości maksimów charakterystyk. Obniżenie częstości drgań własnych belki nastąpił w wyniku obniżenia jej sztywności dynamicznej i w wyniku zmian energii dyssypowanej wewnętrznie. Maksima dla wysokich obciążeń charakteryzowały proces pękania i łamania belki.

Słowa kluczowe: stan degradacji, zmiany strukturalne, sztywność dynamiczna, belka struno-betonowa.

1. ANALYSIS OF DEGRADATION PROCESS OF MECHANICAL OBJECT

In order to assess the dynamic condition of a machine, knowledge of dissipated power is required (real parts of dynamic load power) as well as separation of the power of inertia force and dynamic rigidity power (imaginary parts of dynamic load power).

The machine which dynamic characteristics in terms of frequency are described by matrix H, is exposed to externally forcing vector (F). The answer vector of vibration rate (Vi) is calculated. The dynamic load power distribution matrix (Nik) is defined as the quotient of vector of vibration rate (Vi) and transposed forcing action vector (Fk).

Elements of the dynamic load power distribution matrix (Nik) are the function of dynamic time (t) and evolution time of condition ().

The model takes into account changes of the object dynamic properties and increase of vibration quantity amplitudes. The changes occur because of destruction process taking place during the object exploitation. Base element of evolution destruction process is energy dissipation phenomenon.

Evolution of wear and machine part damages needs to build an energetic model that describes the machine behavior vs. dynamic evolution time (long time Θ) in all lifetime of the machine.

A discrete dynamic machine MIMO model can be described by the matrix equation of motion:

$$\{M[D(\Theta)]\ddot{x}(t,\Theta)+C[D(\Theta)]\dot{x}(t,\Theta)+ \\ +K[D(\Theta)]x(\Theta,t)\}^{T}\dot{x}(t,\Theta)=F^{T}(t,\Theta)\dot{x}(t,\Theta) \quad (1)$$

where:

M, C, K - mass, dumping and stiffness matrices,
F(t) - excitation vector,
$\ddot{\mathbf{x}}(t), \dot{\mathbf{x}}(t), \mathbf{x}(t)$ - acceleration, velocity and displacement vectors,
T – denotation of matrix or vector transform.

Term $F^T(t,\theta)\dot{X}(t,\theta)$ presents matrix of input power "supplied" to the system as result of the loading force vector $F(t,\theta)$, matrix of the dumping force power $\{C[D(\theta)]\dot{X}(t,\theta)\}^T \dot{X}(t,\theta)$ is a power dissipated by dumping C, and internal power of the structure is stored interchangeable by inertial force power $\{M[D(\theta)]\ddot{X}(t,\theta)\}^T \dot{X}(t,\theta)$ and dynamic stiffness power $\{K[D(\theta)]X(t,\theta)\}^T \dot{X}(t,\theta)$.

In terms of frequency, the load power distribution is described by formula (1), where the elements of dynamic characteristics are the functions of destruction's measurements (formula 2).
Elements on the main diagonal of the powers loads distribution matrix are the characteristics of the dissipated power in a machine. The odd elements are the compound values. Imaginary parts are measurements of power. They carry as a result of impact of each force applied to the machine at points k and nominated at nodal points i.

The powers $\mathrm{Re}\,\overline{GN}_{kk}(\Theta)$, being real values, are a measure of dissipated powers; the powers $\mathrm{Im}\,\overline{GN}_{ik}(\Theta)$, $i \neq k$, are force powers of dynamic rigidity and inertia of mechanical structures transferred to spots "*i*".

2. STRUCTURAL CHARACTERISTICS OF PRESTRESSED CONCRETE BEAMS

The examples of application of dynamic load power method for object technical state description and structural parameters changes in process of its degradation will be presented.

The diagnostic tests have been made concerning the technical condition of the beams subjected to forcing actions applied in sequence in escalating degradation stages as a result of successively succeeding dynamic loads F, put in the middle of the beam: 0 – 24 kN.

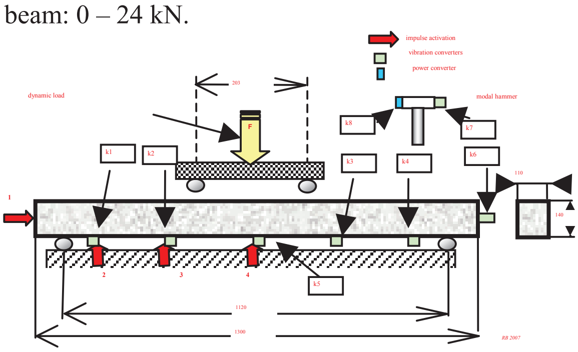

Fig. 1. Location of testing points of vibration acceleration and points subjected to forcing actions by a modal hammer

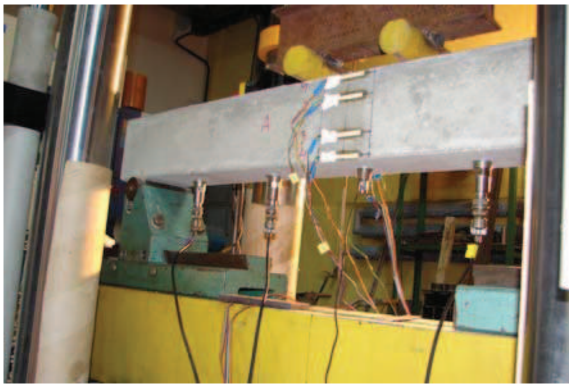

Fig. 2. Beams have been subject to dynamics load until their crack

The figures below (fig. 3 - 9)) presented the comparison of the testing load power spectral density power GN of the beams, determined in particular conditions of the technical degradation of the object. The dynamic characteristics and the testing load vibrating power values reflect the intensity of beams' degradation (cracking).

The state of beams degradation, caused by the increase of the dynamic load, manifests itself in reduction of characteristic maxima frequency which means reduction of vibration frequency of the beams as a result of reduction of their dynamic rigidity and change of the internally dissipated energy and change of the internally dissipated energy. On the basis of the analysis of the changes of energetic modes extremes (imaginary parts of the power spectral density of the testing loads power) relevant changes (decrease or increase) of the beam's dynamic rigidity have been determined. Frequency, damping changes and dynamic rigidity in mechanical object posing the mechanical system structural degradation were defined.

Damping changes are different for particular energetic modes. The greatest damping changes are observed for the mode of low frequency. On the basis of the analysis of the energetic modes changes relevant changes (increase or decrease) of dynamic rigidity of particular beams as a result of their degradation have been determined.

The square of the frequency of natural damped vibrations of energetic mode of a mechanical object is as follows:

$$\sigma_i^2 = \omega_{0_i}^2 - h_i^2 \tag{2}$$

where:

ith energetic mode of the object, ω_{0_i} – the frequency of natural undamped vibrations of ith energetic mode, h_i – damping measure of ith mode.

Table 1. Dynamic loads - technical condition changes of the steel concrete composite beam

transverse load [kN]	number of cycles	observation of the beam degradation condition	frequency **1 mode** 140 - 210 Hz	frequency **2 mode** 700 -1000 Hz	frequency **3 mode** 2100 - 2600 Hz
2	*3*	*4*	*5*	*6*	*7*
0	0	no fractures	176,5	928,1	2429,6
0 – 4	200	no fractures	181,2	926,6	2425,0
0 – 6	200	no fractures	182,8	926,6	2418,4
0 – 8	200	no fractures	184,4	925,0	2414,1
0 – 10	200	no fractures	184,4	925,0	2414,1
0 – 12	200	no fractures	184,4	925,0	2414,1
0 – 14	200	no fractures	182,8	921,8	2407,0
0 – 16	200	first fractures were shown at the bottom and on the side surfaces of the beam - fractures reach 1/3 cross - section	179,6	915,6	2396.8
0 – 18	40	the same amplitude 16 kN (to high frequency)			
0 – 18	50	further propagation of the fracture which reaches 3/4 cross - section on the side surfaces of the beam	175,0	904,6	2362,4
0 – 18	150	as above	175,0	900,0	2342,2
0 – 20	200	fracture on the side surfaces of the beam reaches 4/5 cross – section	171,8	886.0	2310,0
0 – 22	115	as above			
0 – 22	85	as above	168,8	870,2	2248,4
0 – 24	100	width of the fracture (spread) increase at the bottom			
0 – 24	100	as above	167,2	858,0	2189,0

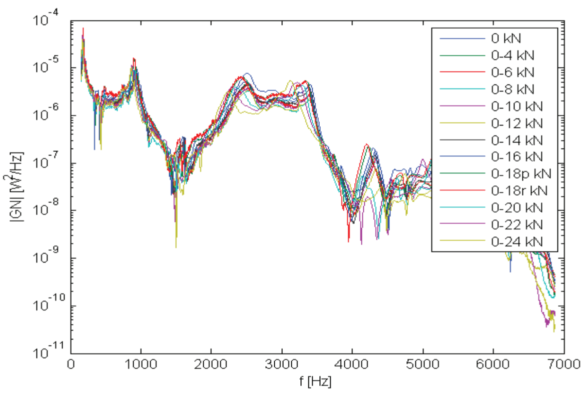

Fig. 3. Absolute values of GN(f) beam testing load power spectral density power

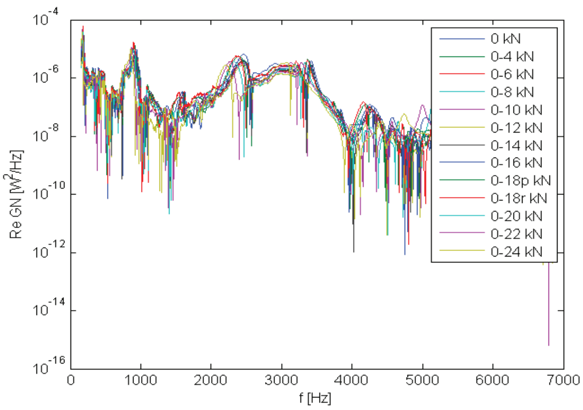

Fig. 4. Real parts of GN(f) beam testing load power spectral density power

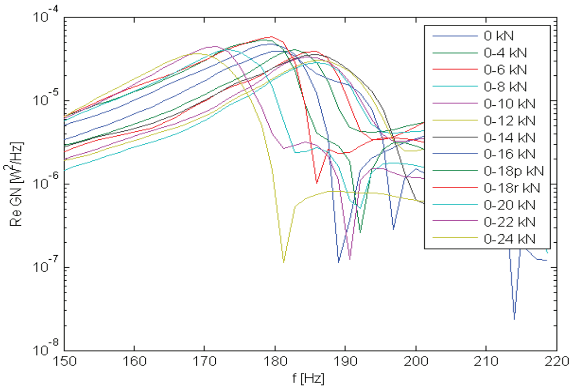

Fig. 5. Real parts of GN(f) beam testing load power spectral density power

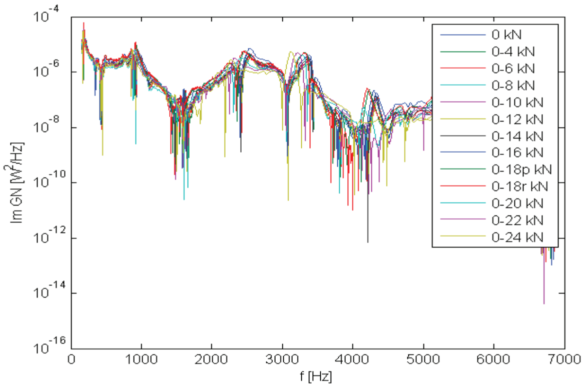

Fig. 6. Impulse loads power spectral density imaginary parts changes, describing object structural degradation (scope 30-7000 Hz)

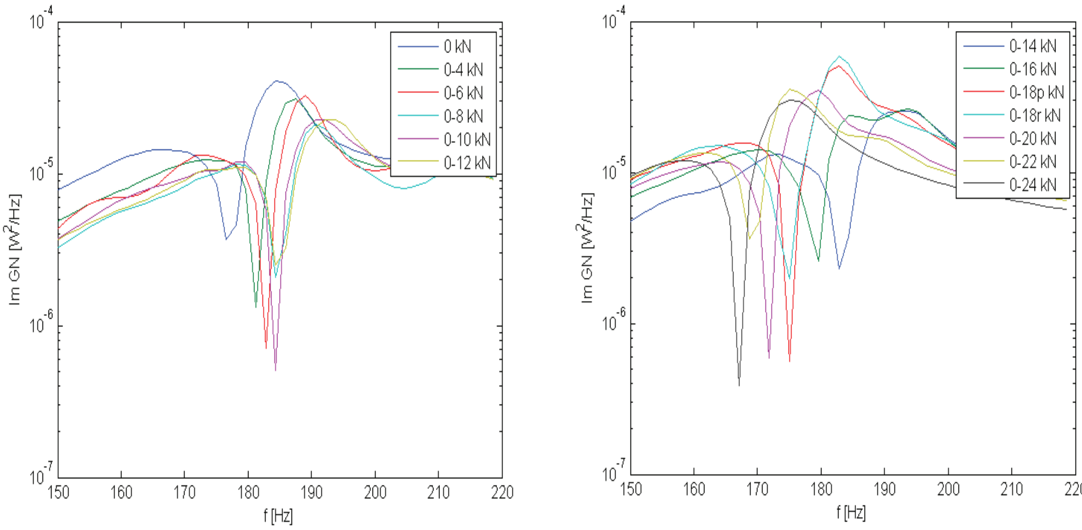

Fig. 7. Impulse loads power spectral density imaginary parts changes, describing object structural degradation (scope 150-220 Hz)

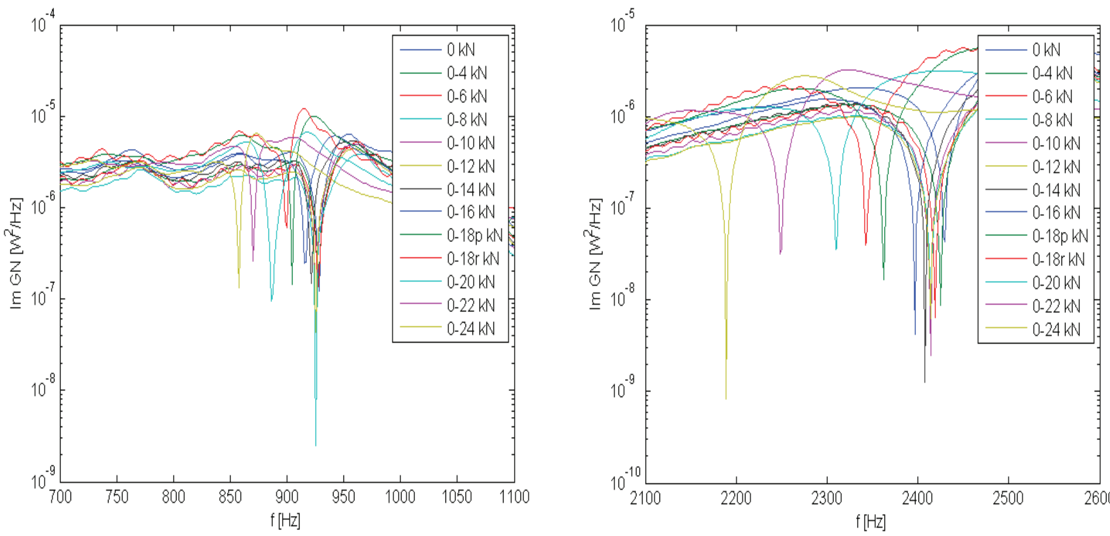

Fig. 8. Impulse loads power spectral density imaginary parts changes, describing object structural degradation

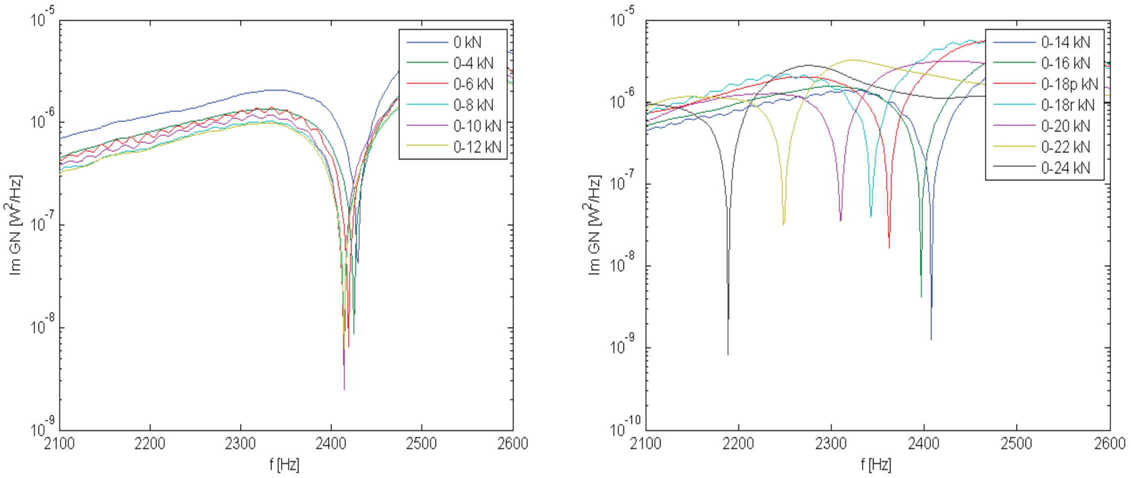

Fig. 9. Impulse loads power spectral density imaginary parts changes, describing object structural degradation (scope 2100-2600 Hz)

As a result of the process of technical degradation of a mechanical object there was a decrease of the frequency of modes (reinforcing of the beam's rigidity) or an increase of the frequency of modes.

The value of a relevant change (decrease, increase) of dynamic rigidity of a mechanical object as a result of its structural degradation is received:

$$\frac{k_i - k_r}{k_i} \approx 1 - \frac{\omega_{0_r}^2}{\omega_{0_i}^2} \quad [\%] \qquad (3)$$

On the basis of the analysis of the energetic modes changes (fig. 10 - 11) relevant changes (increase or decrease) of dynamic rigidity of particular beams as a result of their degradation have been determined (fig. 12).

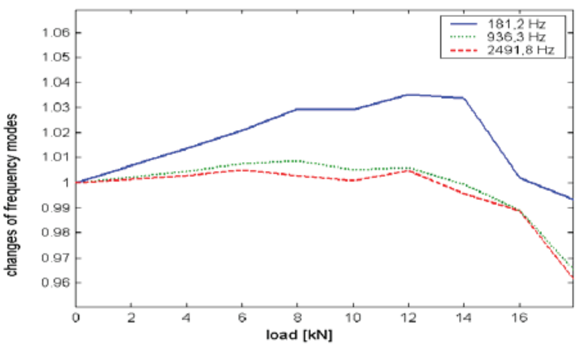

Fig. 10. Changes of frequency of modes

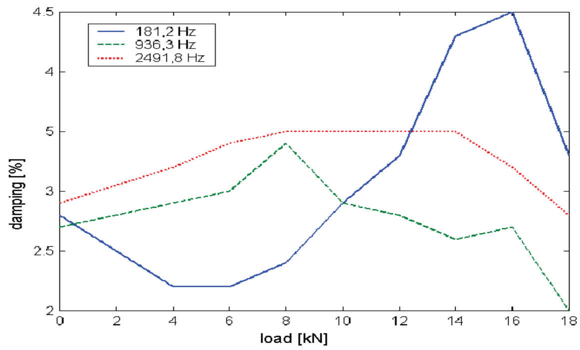

Fig. 11. Energetic modes damping changes resulting from beam degradation

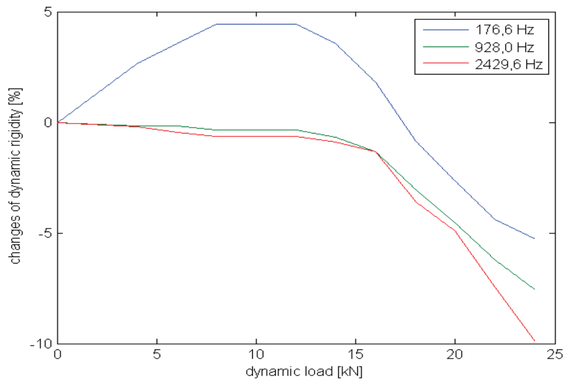

Fig. 12. The changes of dynamic rigidity of a pretensioned prestressed concrete beam as a result of a degrading dynamic load

3. CONCLUSION

1. The processes determining the machine life characteristic and the measures of changes of its technical state have an energetic dimension. Therefore, one should use energetic methods in performing tests in the field of rigidity of mechanical objects.

2. In order to assess the dynamic condition of a mechanical system, it is required to know dissipated power (real parts of dynamic load powers) and separate the powers of inertia forces and dynamic rigidity forces (imaginary parts of dynamic load powers). The method is applied in research into energy dissipation and structural changes in mechanical objects.
3. Vibration damping is a value posing the initial degradation and structural stage of mechanical object. Dynamical rigidity changes, appearing as cracking, occur mainly in the second – final stage of mechanical object technical degradation. Analysis of the changes enables determinig loads power limiting values, causing mechanical object element structural degradation processes initiation

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Doc. dr hab. **Henryk KAŹMIERCZAK** – absol-went Wydziału Mat. Fiz. Chem. Uniwersytetu im. Adama Mickiewicza w Poznaniu, stopień doktora nauk technicznych uzyskał w 1977r. na Wydziale Budowy Maszyn Politechniki Poznańskiej. Stopień doktora habilitowanego nauk technicznych z dziedziny mechanika uzyskał w 2002r. na Wydziale Budowy Maszyn i Zarządzania Politechniki Poznańskiej. Jest autorem ponad 250 publikacji naukowych. Zajmuje się zagadnieniami z dziedziny dynamiki maszyn, diagnostyki technicznej, identyfikacji własności dynamicznych maszyn, w tym metodami analizy modalnej.

Dr inż. **Tadeusz PAWŁOWSKI** – dyrektor Przemysłowego Instytutu Maszyn Rolniczych w Poznaniu. Absolwent Politechniki Poznańskiej, autor lub współautor ponad 80 prac naukowych z zakresu nowoczesnych metod analiz wytrzymałości konstrukcji, symulacyjnego szacowania obciążeń dynamicznych konstrukcji nośnych, analizy funkcjonalnej maszyn i urządzeń, komputerowego wspomagania projektowania (CAD) oraz projektowania napędów hydrostatycznych w maszynach rolniczych.

Dr **Jacek KROMULSKI** jest adiunktem w Przemysłowym Instytucie Maszyn Rolniczych. W działalności naukowej zajmuje się zagadnieniami dynamiki strukturalnej, modelowania, analizy modalnej oraz analizy sygnałów. Jest autorem ponad 80 prac dotyczących tych zagadnień.

Dr inż. **Roman BARCZEWSKI** jest adiunktem oraz kierownikiem Laboratorium Diagnostyki Systemów w Instytucie Mechaniki Stosowanej Politechniki Poznańskiej. Specjalizacja: diagnostyka i wibroakustyka maszyn i środowiska badania drgań i hałasu, techniki i diagnostycznie zorientowane medody cyfrowego prztwarzania sygnałów WA; samouczące i samoorganizujące systemy diagnostyczne.