Politechnika Wrocławska

Digital Mining Center

MOIRA TRAINING NETWORK

DYNAMICAL MODELS IN DIAGNOSTICS OF INDUSTRIAL MACHINES

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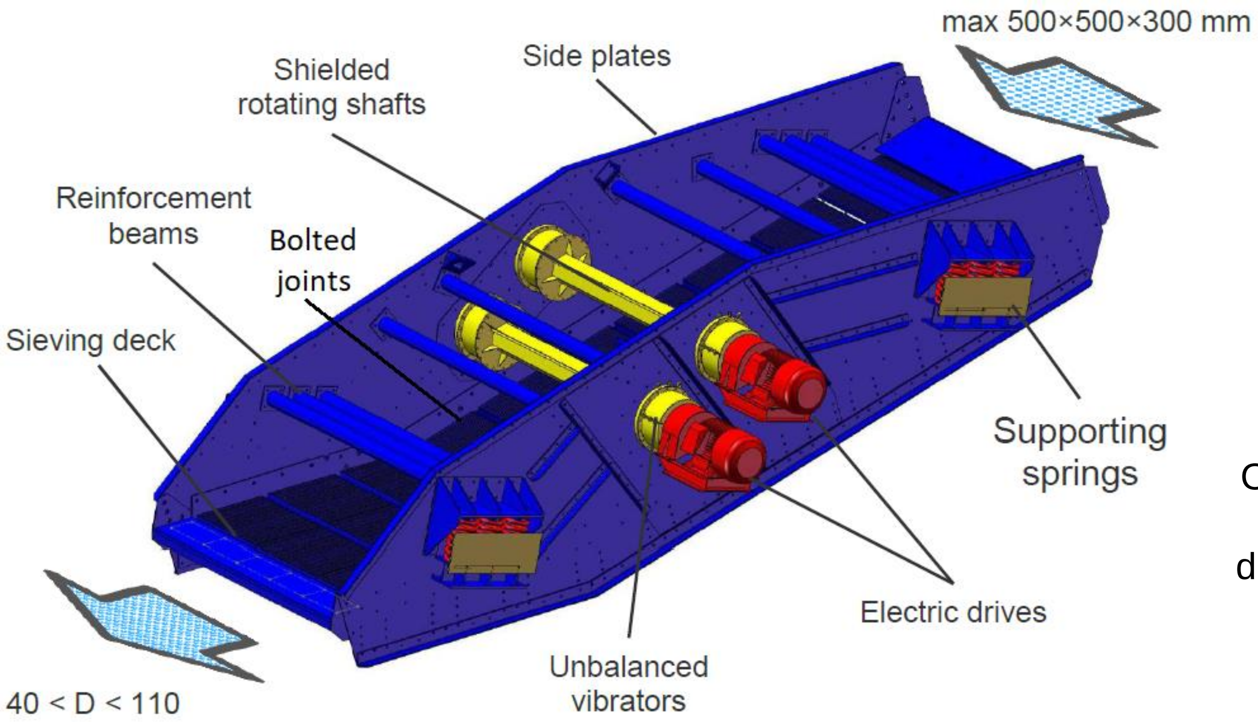
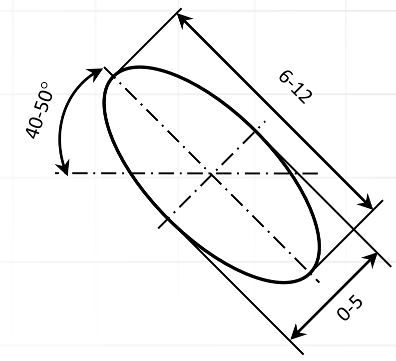
HR EXCELLENCE IN RESEARCH

Scope

1. Vibrating screens
2. Types of failures
3. Dynamics and excitation
4. Diagnostics of main elements
5. Conclusions

Typical sieving screen

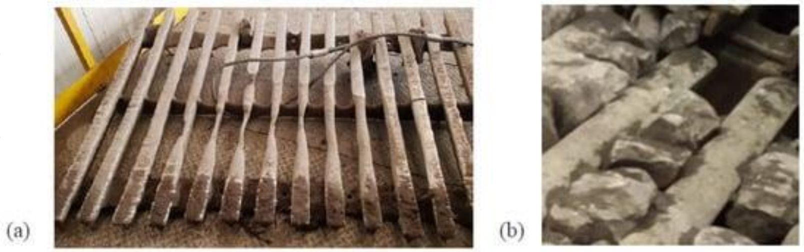




Orbit is the main technological parameter, its form and size depends on screen design and vibration excitation forces

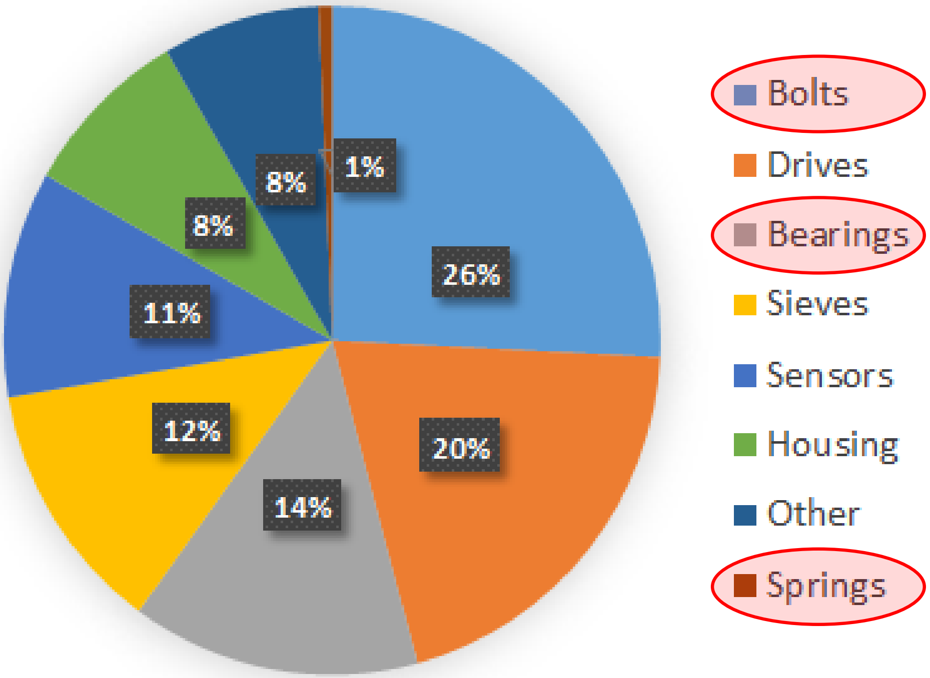
All components of any vibrating screens are subjected to wear, fatigue and failures

Screen failures



Severe abrasive wear of beams and blinding with a sieved material.

The oversized pieces of material cause failures and create non-Gaussian impulsive noise in signals.



Although springs are less susceptible to failures, degradation of their stiffness greatly affects the trajectory of particles and screen.

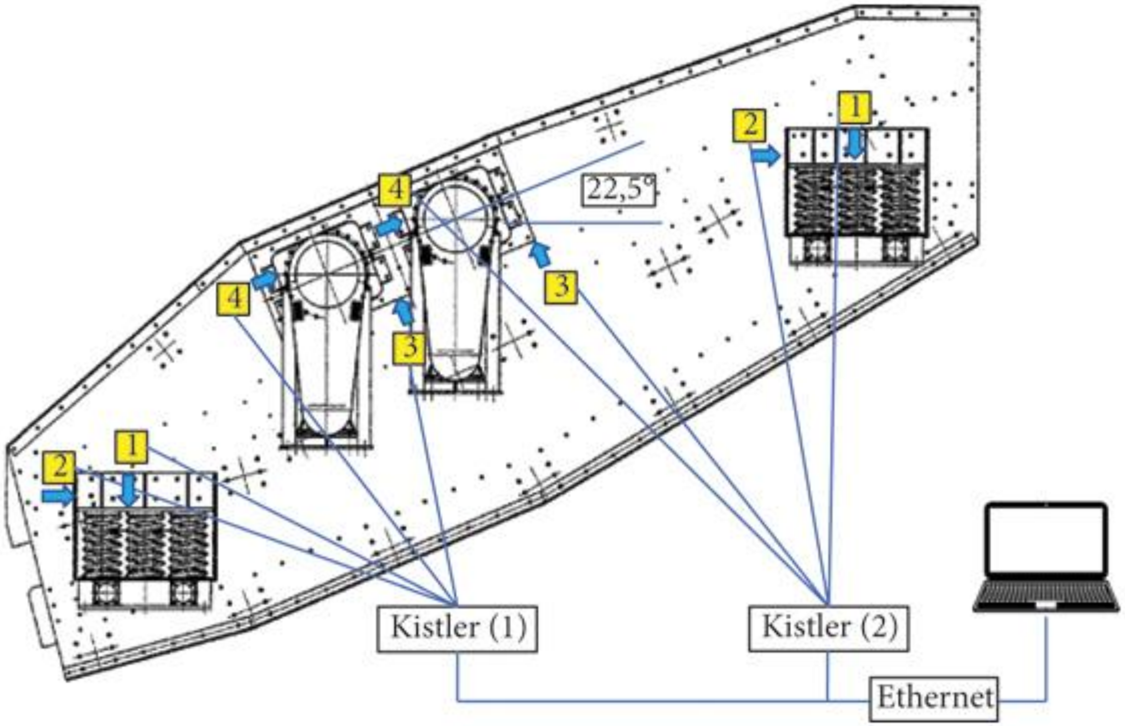
Monitoring and diagnostics of screens

- Significant transient resonant vibrations at drives stops
- Extra power is required to prevent Sommerfeld effect at drives start
- Variability of signals due to changes in material properties
- Non-stationary and impulsive signals require special methods of analysis
- Strong non-linear relationships between loads and elements' wear
- Harsh working conditions and lack of reliable sensors

Our approach

- Clearances are considered the main factors of machines reliability
- Contact gaps should be monitored along with local defects
- Using transient regimes for wear diagnostics in machines
- Dynamical models allow predicting failures without sensors in elements
- Non-linear features in screen dynamics reflect the wear of elements
- The response of a linear system is a reference value in diagnostics

Vibration measurements

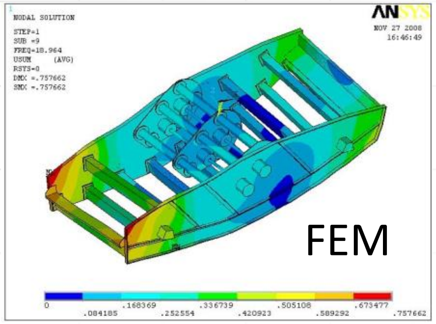


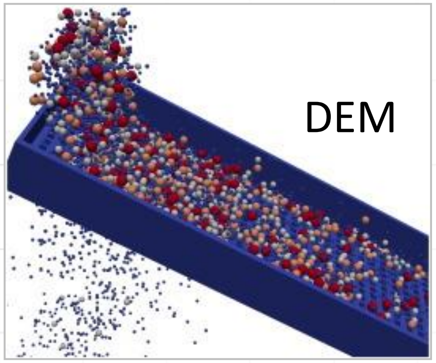
Industrial screen

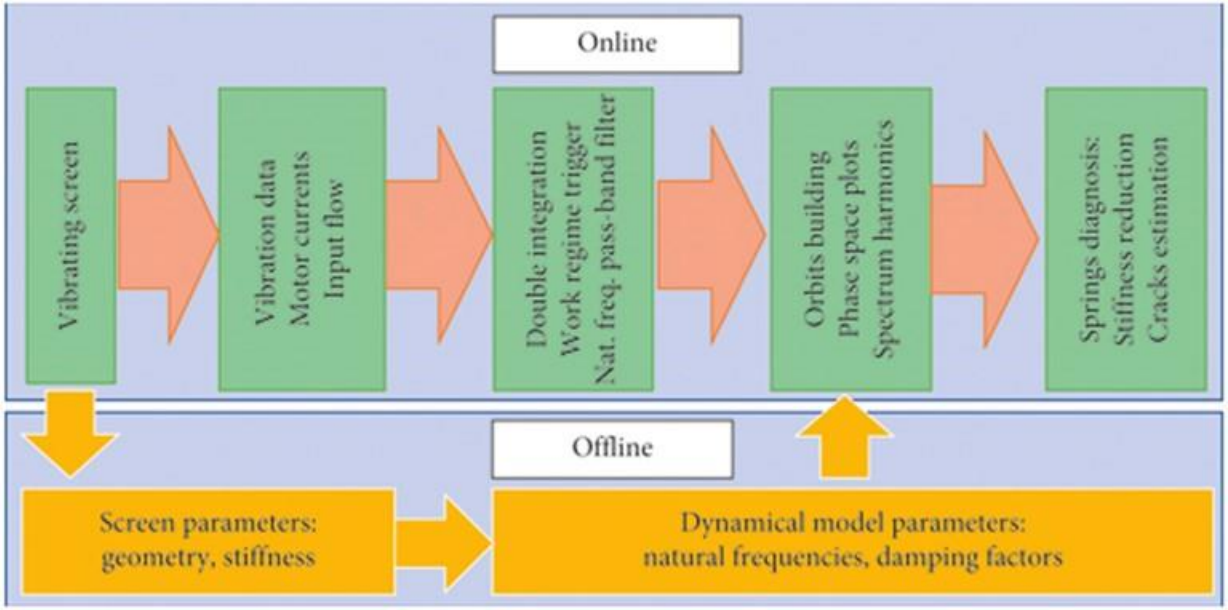
Laboratory screen

Accelerometers with a standard range are used on magnetic bases.

Modelling of screens



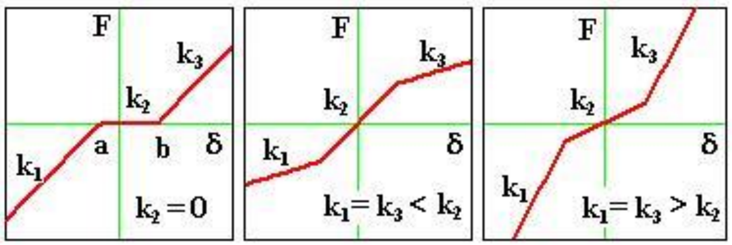




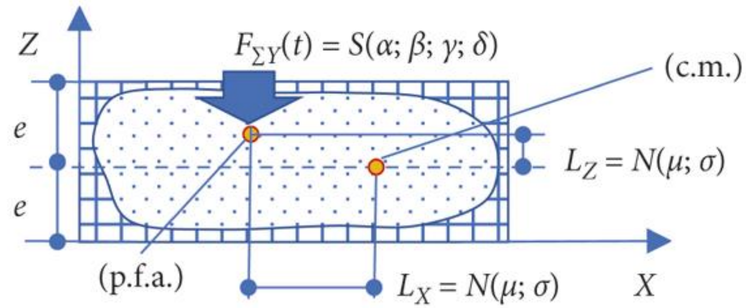
Scheme of (2…6)-DOF dynamical models application

FEM is effective for only new screen calculations but very time-consuming for the entire machine simulation with wear of parts. DEM is mainly applied for screen performance optimization. While reduced order dynamical models can reflect main screen motions and natural modes are sensitive to appeared non-linearity.

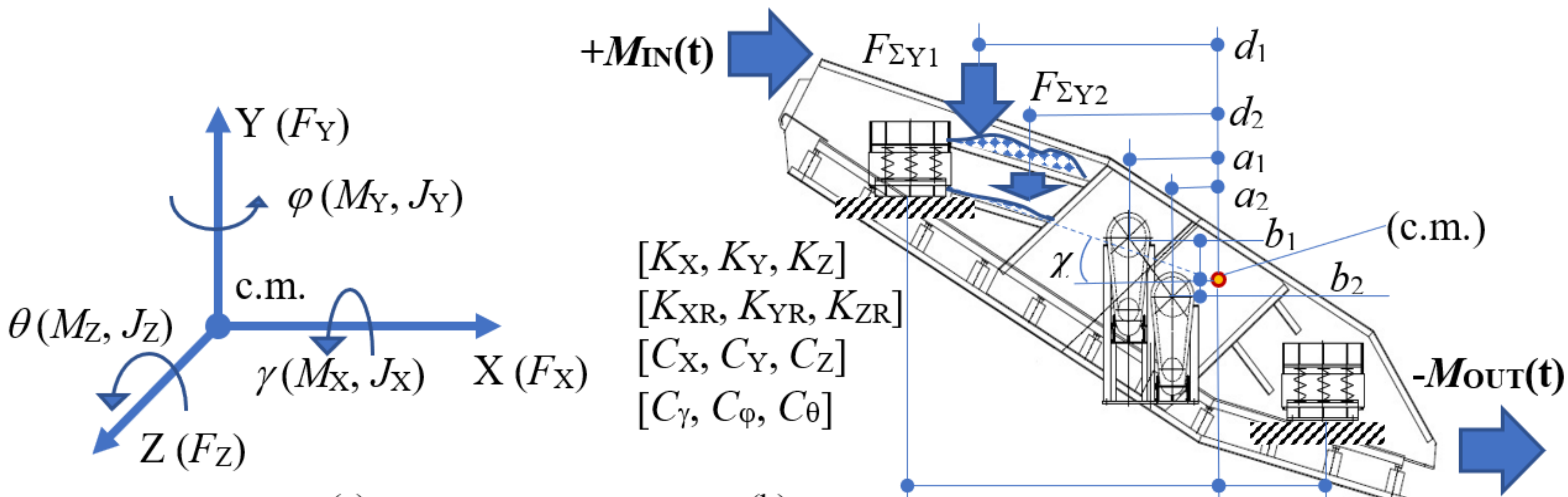
Diagnostics of springs (6-DOF model)



Non-linear stiffness characteristics



Alfa-stable and normal load distribution



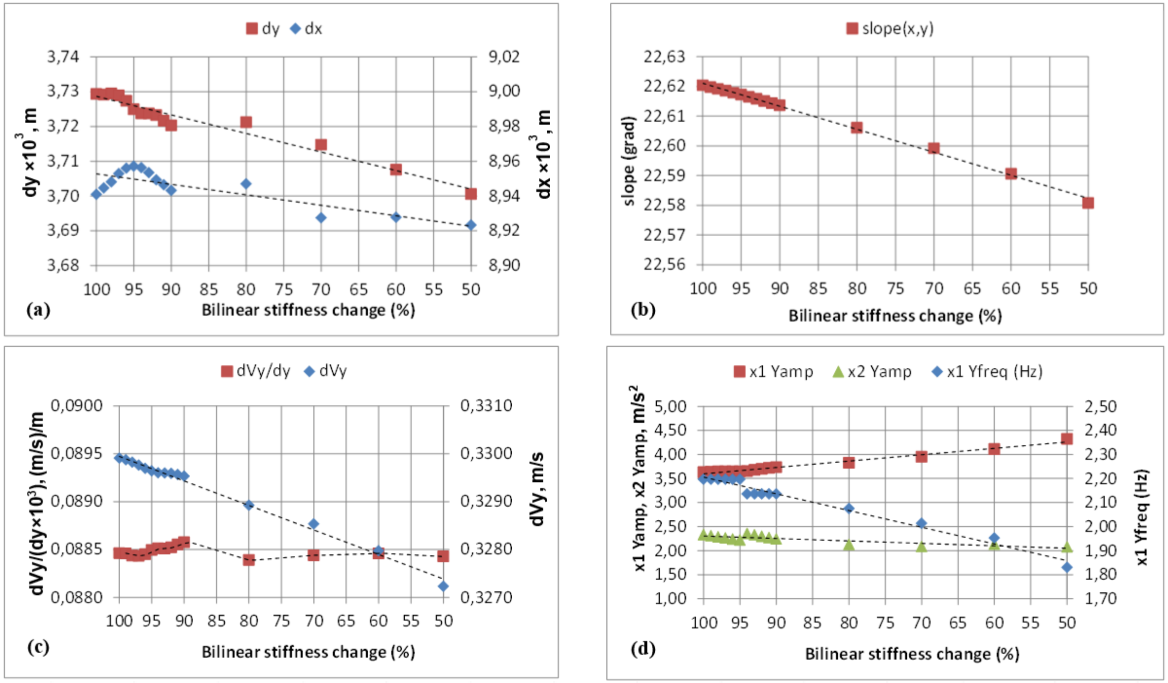
(a) (b)

The resonant frequencies and damping are identified by the transient vibration from the falling pieces of a sieved material.

Diagnostics of springs

Diagnostic parameters:

a) orbit size;
b) orbit slope angle;
c) phase space plot;
d) natural frequency and amplitudes of harmonics.

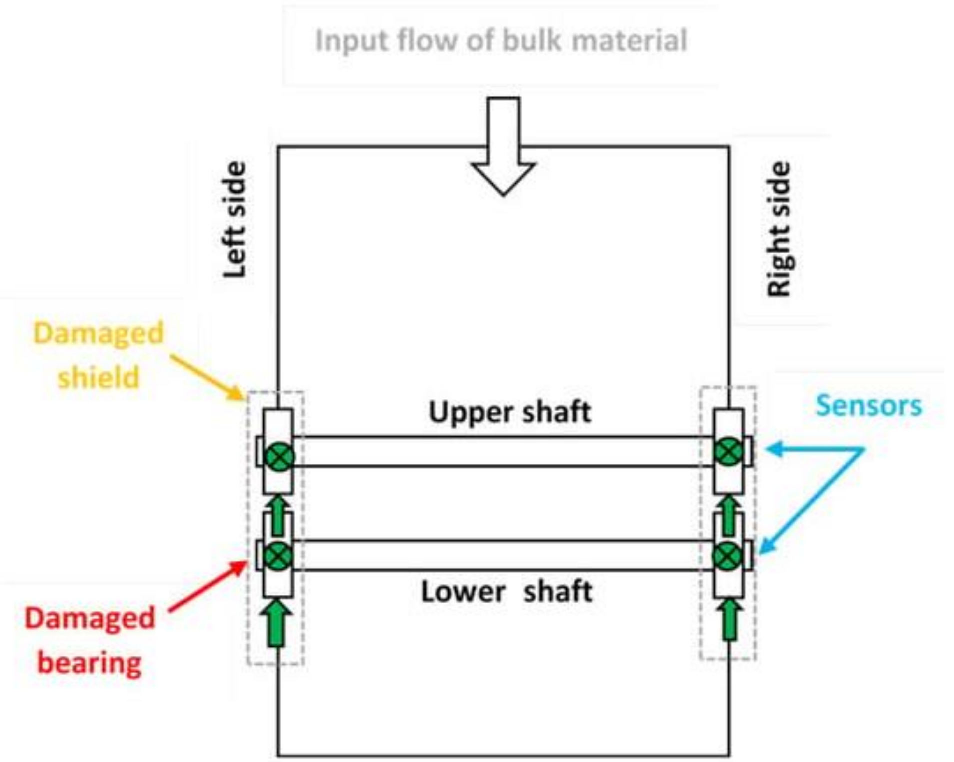


P. Krot, R. Zimroz, et al. (2020) Development and Verification of the Diagnostic Model of the Sieving Screen, Shock and Vibration, 8015465.

Almost all diagnostic parameters have linear relation with spring stiffness change. Due to low-frequency range (1–2 Hz) of natural frequencies, their identification and separation need special types of vibration sensors.

Diagnostics of bearings

Inner ring's pitting (about 120° length)



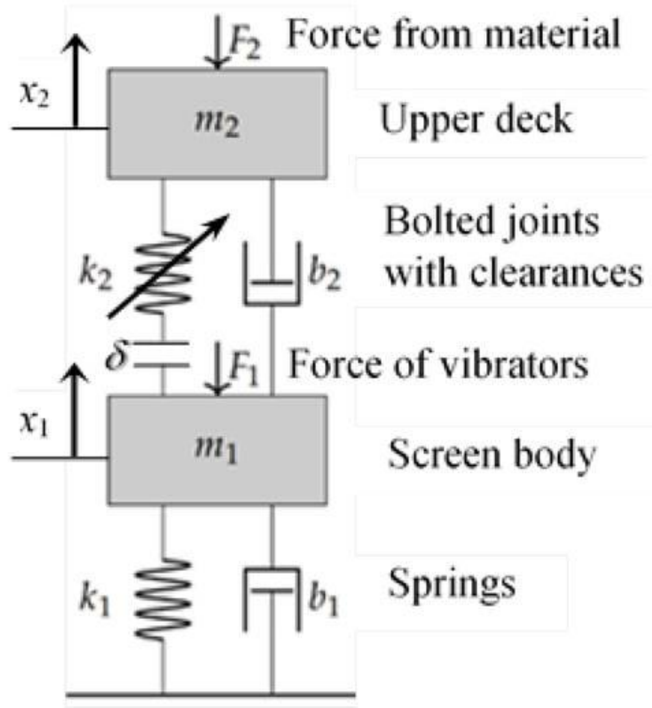
Wodecki J., Krot P., Wróblewski A., Chudy K., Zimroz R. Condition monitoring of horizontal sieving screens – a case study of inertial vibrator bearing failure in calcium carbonate production plant. *Materials*. 2023, 16(4):1533.

Diagnostics of bearings – methods comparison

Methods and parameters	Before repair	After repair	Relative change
Time Series: RMS value, g	11.71	3.77	-68%
Time–Frequency Spectrogram: Median energy, dB	−27.8	-52.5	89%
Cyclic Spectral Coherence:: Amplitudes ratio at frequencies (f_d/f_c)	1.0	0.16	-85%
Envelope spectrum: Average amplitude, g^2	0.005	0.001	-80%
Orbit: Angle of inclination, grad	40.22	46.65	16%
Length, mm	6.3	3.3	−48%
Width, mm	2.6	0.1	−96%
Phase Space Plot (PSP): Horizontal size, mm	5.84	2.38	−59%
Vertical size, m/s	0.09	0.03	−67%
Form factor (V/H), 1/s	15.3	11.0	−28%

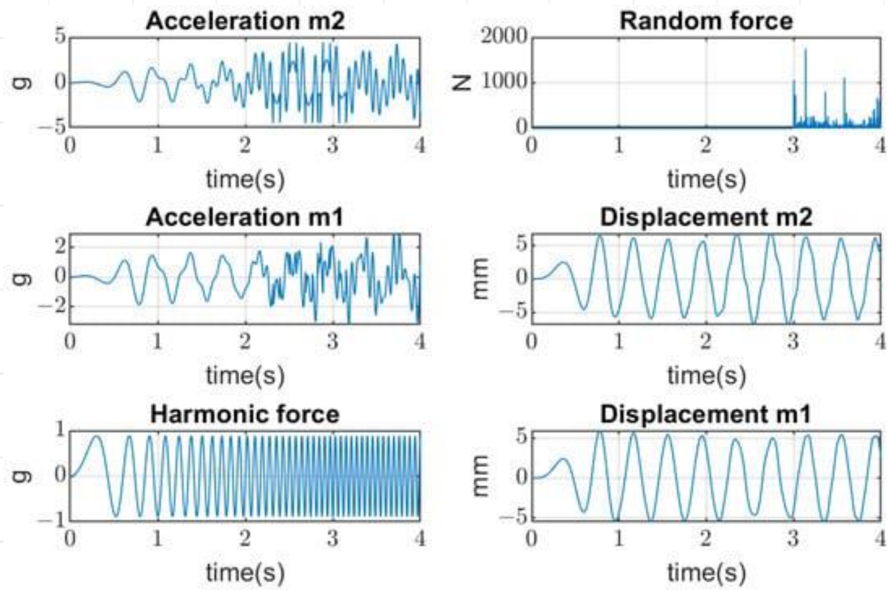
The most sensitive occurred width of orbit (-96%) and median energy of spectrogram (89%). The next rated are cyclic spectral coherence (-85%) and enveloped spectrum (80%). Time domain parameters (RMS, orbits, PSP), although are briefly less sensitive (60-70%) but require less data and much slower sampling, hence, are more suitable for online monitoring.

Diagnostics of bolted joints

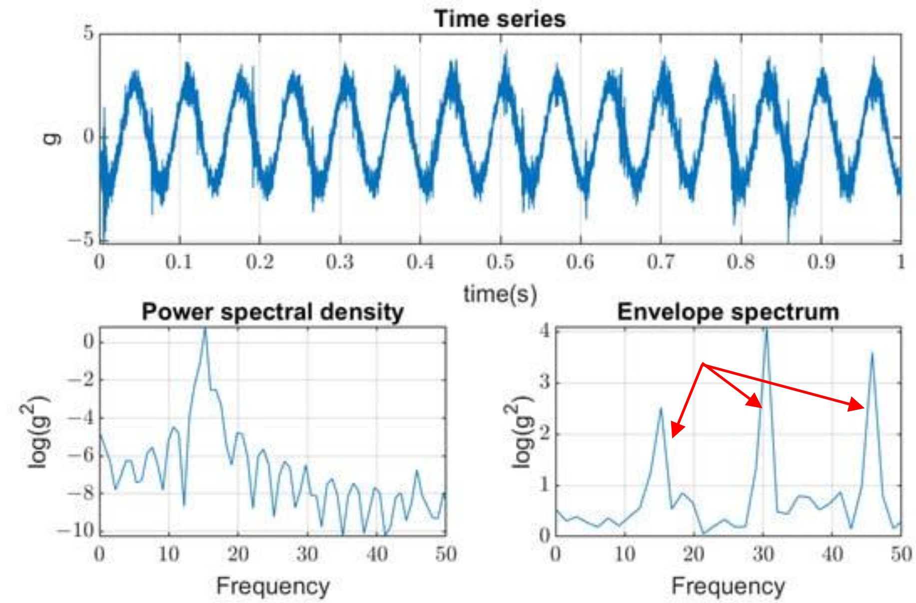


When bearings of screen vibrators are in bad condition, they produce higher harmonics of rotation frequency in the excitation force, which can coincide with the second natural mode of the screen under certain its design parameters. This effect will lead to higher tension of bolts (out-of-phase vibration), plastic deformations and gaps opening in joints.

Vibration signals

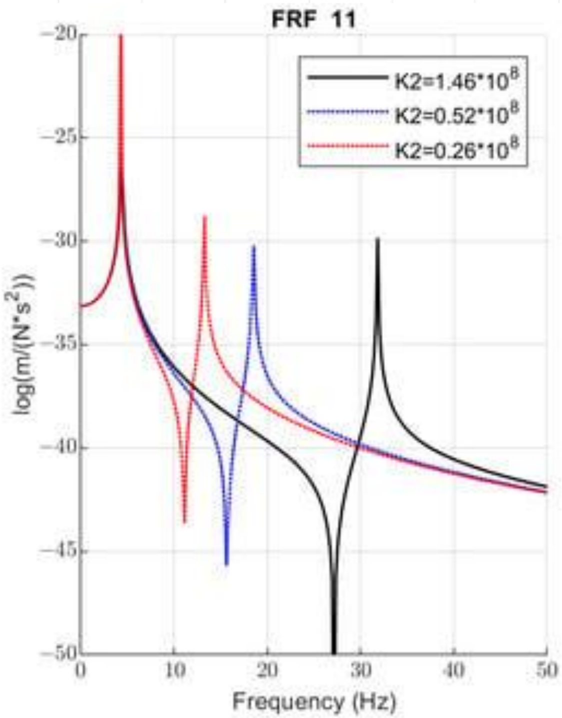


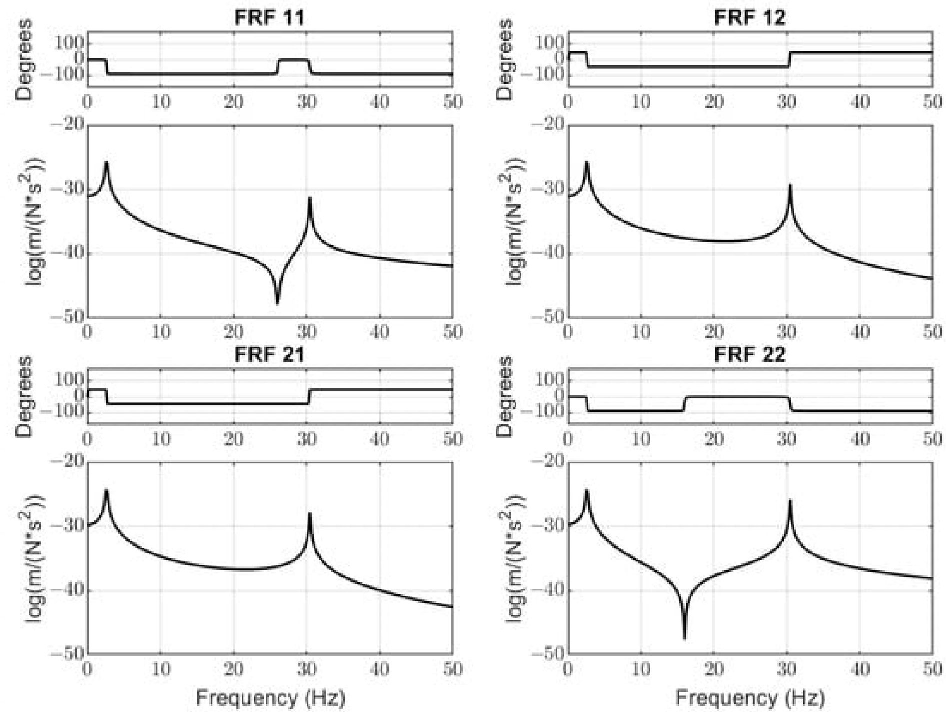
Simulation of screen start



Vibration measurement on the screen with bad condition of bearings

Frequency response functions (FRF)





Stiffness of bolts (k_2) causes deviation of 2nd natural mode frequency, while the 1st mode does not react to joints looseness. Also, the anti-resonance is discovered, which can lead to drive energy leak if their frequencies coincide.

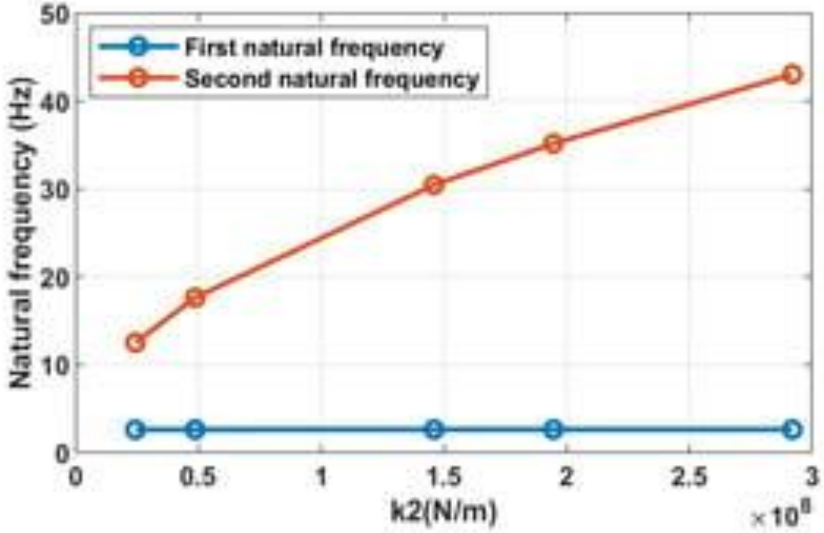
*FRF*11 = (displacement of mass m_1) / (vibrators' force F_1)

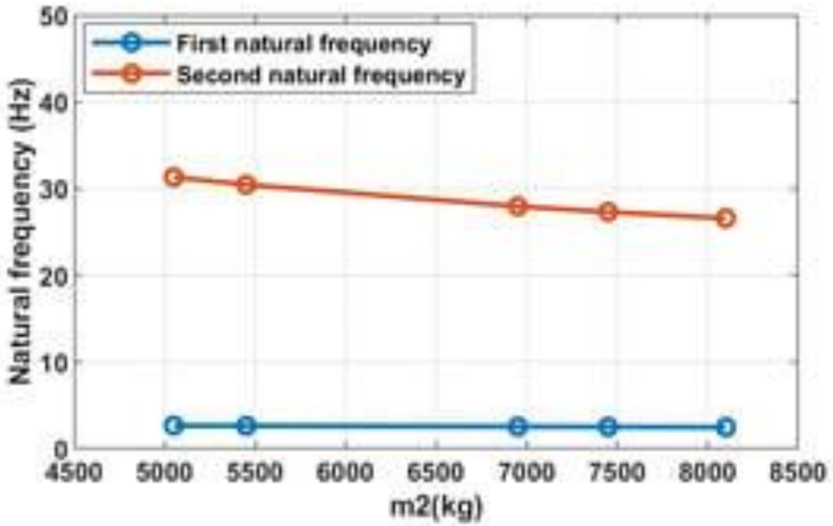
*FRF*12 = (displacement of mass m_2) / (vibrators' force F_1)

*FRF*21 = (displacement of mass m_1) / (material impacts force F_2)

*FRF*22 = (displacement of mass m_2) / (material impacts force F_2)

Detuning from the resonance

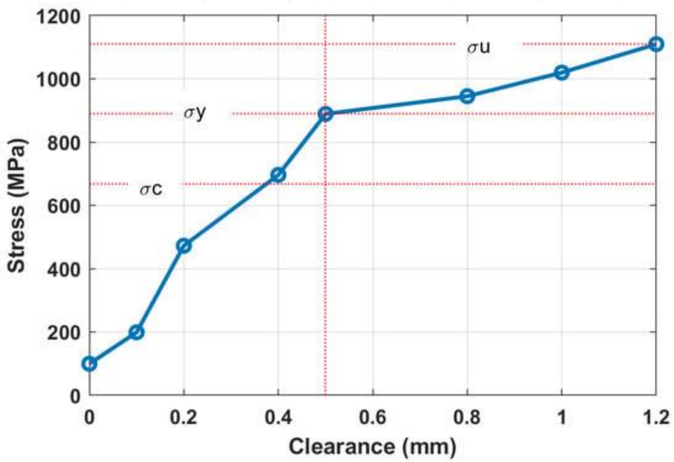




Dependence of the natural modes' frequencies on the stiffness k_2 of bolted joints and mass m_2 of upper deck. The first natural mode frequency is almost insensitive to those parameter changes.

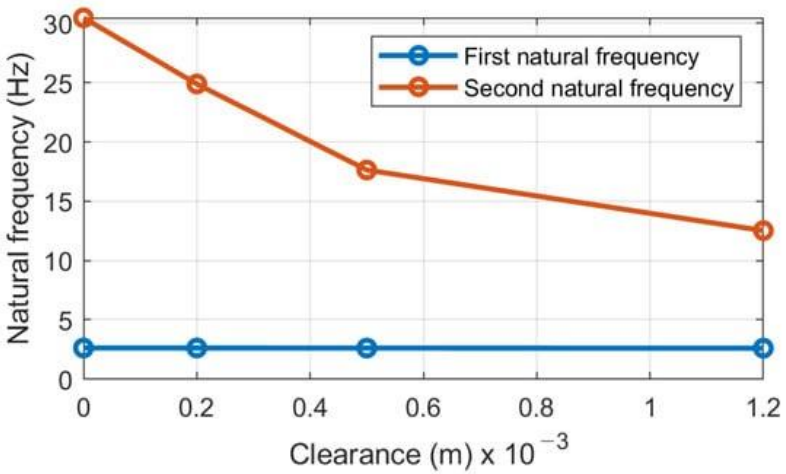
To tune out the vibrating screen from the resonance by the second natural mode around the 2×, 3× harmonics (30, 45 Hz) of the main excitation frequency (15 Hz), it is required to change the total stiffness of bolted joints by 2.63×10^7 N/m, which corresponds to the frequency deviation by at least ±3 Hz.

Dynamic loading in bolted joints



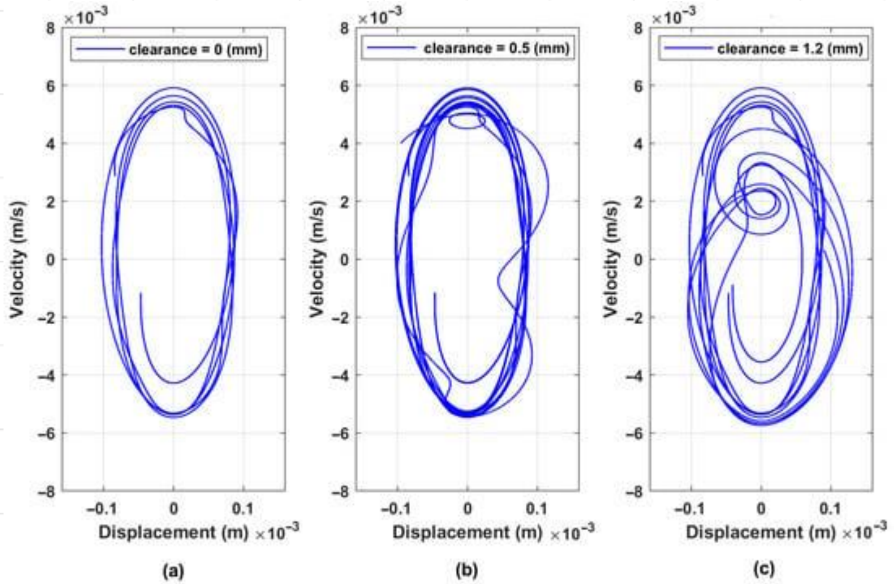
Tensile stress relation with bolted joint loosening between the upper deck and the screen body.

The vertical line shows a maximum allowable clearance (0.5 mm), which corresponds to a yield stress σ_Y in the bolts (pre-tightening stress σ_C and ultimate stress σ_U of bolts failure are also shown).

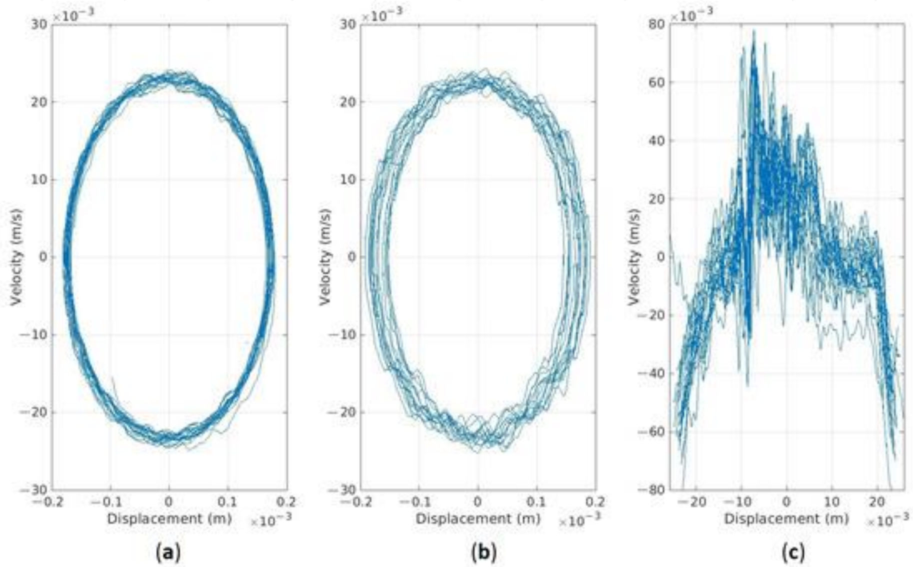


The sensitivity of the 1st and 2nd natural mode frequencies to the clearance in the bolted joints.

Phase space plots (PSP)

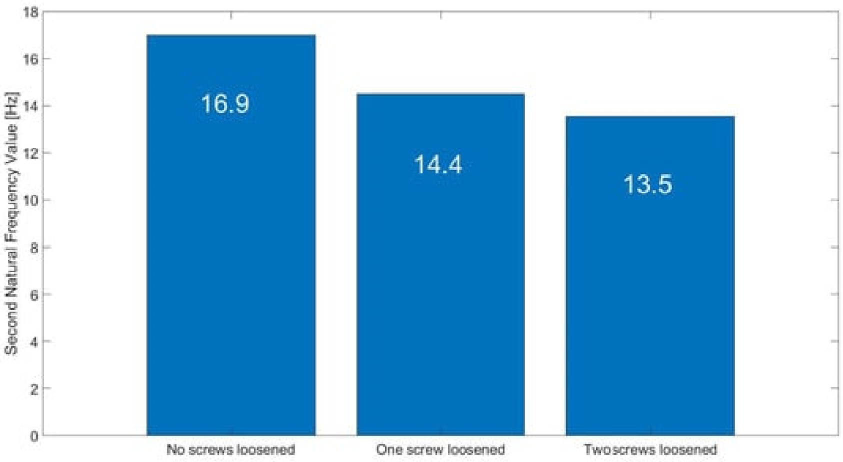


Simulation of bolts loosening

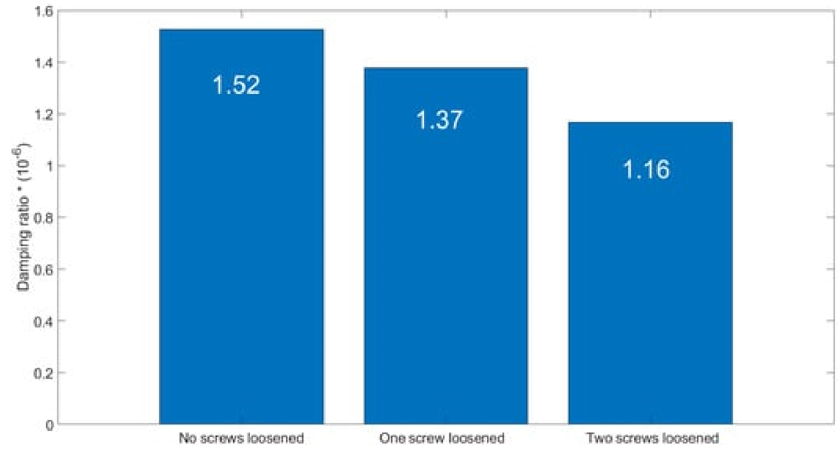


Measurement on the screen for three grades of bolts loosening

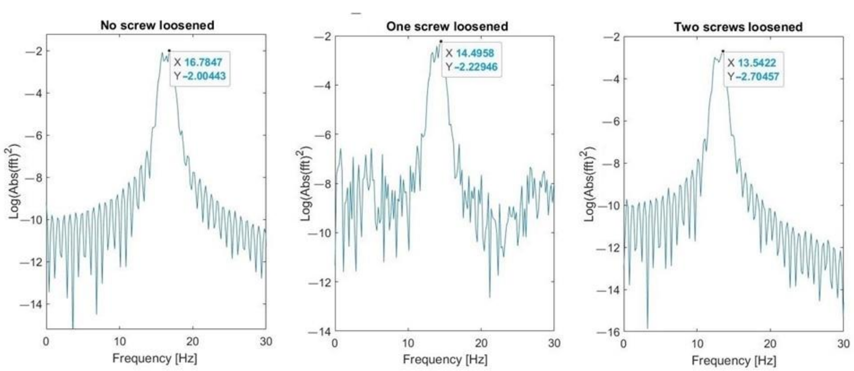
Diagnostic parameters of bolted joints

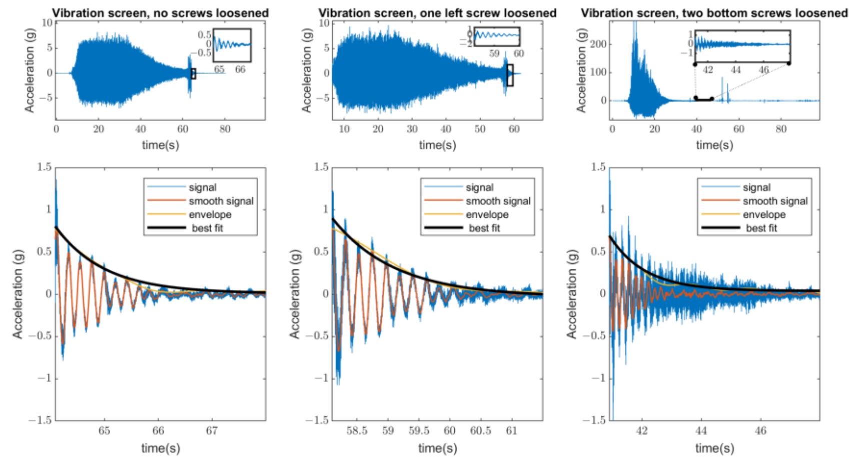


2nd natural mode **frequency**



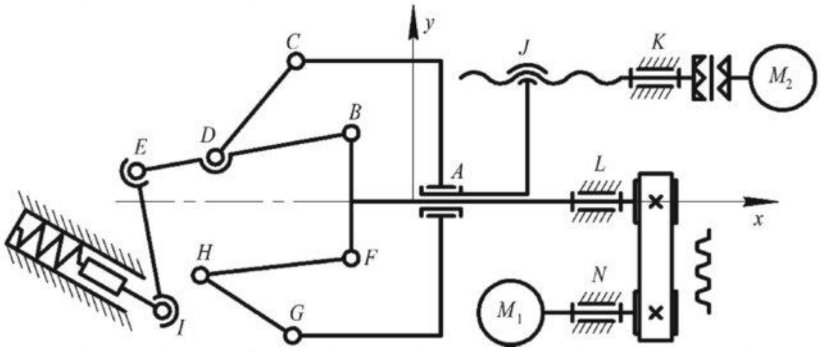
1st natural mode **damping**

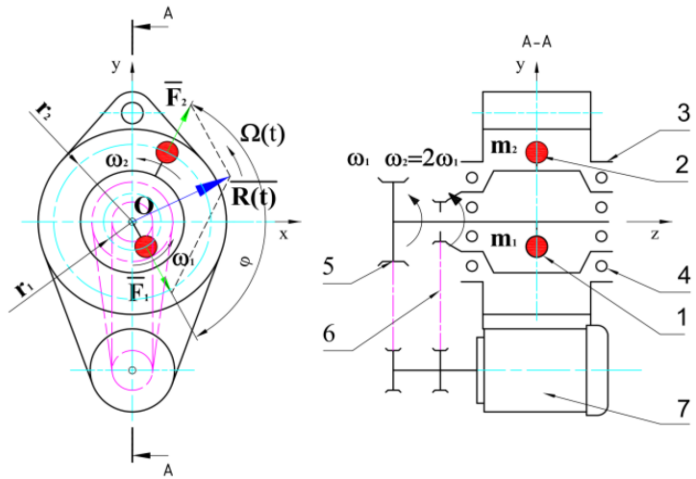




Natural frequency is absolutely robust to periodical disturbance (in a far-above-resonance system) and applied impulsive noise!

Innovative vibration exciters





Crank type mechanism – control of eccentricity and frequency

Lanets O, et al (2021) Controllable Crank Mechanism for Exciting Oscillations of Vibratory Equipment. Advances in Design, Simulation and Manufacturing IV. DSMIE 2021

Coaxial unbalanced rotor - dual-frequency with only one electric motor and kinematic synchronization of rotors

Gurskyi V, et al (2023) On the Dynamics of an Enhanced Coaxial Inertial Exciter for Vibratory Machines. Machines 11(1):97

Multi-frequency exciters of screen vibration are more efficient than classical single-frequency ones. The developed improved vibrators are applicable in various machines. More detailed information is available in the given publications.

Conclusions

- During normal operation, screens are exposed to periodic loading by vibrators (cyclic excitation) and stochastic impacts from sieved material (impulsive non-Gaussian noise).
- Degradation of springs, bearing and bolted joints significantly disturb trajectory (orbit) of screen motion and affect its productivity
- Unavoidable but uncontrolled clearances are considered the main factors of excessive dynamic loads and failures of industrial machines.
- Using reduced order dynamical models allows to detect non-linear features appeared in the machine due to wear of its elements.
- For various elements diagnostics, different dynamical models and natural modes can be used, which are most sensitive to certain defects.
- The multidimensional phase space plots are very sensitive to screen defects and need further development of metrics for quantitative description of trajectories, their implementation in a condition monitoring systems requires only one vibration sensor.
- The developed model-based approach is a basis for building of a new maintenance strategy based on monitoring of fatigue and predicted remaining useful life of machine elements.

Related references

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8. Krot P., Prykhodko I., Raznosilin V., Zimroz R. (2020) Model based monitoring of dynamic loads and remaining useful life prediction in rolling mills and heavy machinery. In: Advances in Asset Management and Condition Monitoring. Smart Innovation, Systems and Technologies, 166, 299-415, Springer, Cham.

Thank you for your attention!