MJERENJE VIBRACIJA TEHNIČKIH SUSTAVA

Ver. 23.03.11.

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S A D R Ž A J

Održavanje po stanju mjerenjem vibracija

Subjektivna ocjena stanja stroja sluh, vid, osjećaj.	do 1960
Konvencionalni nadzor stanja globalno mjerenjem vibracija i usporedbom sa graničnim vrijednostima.	1960-1985
Vibracijsko-dijagnostički nadzor stanja analitičko višefunkcijsko (FFT) mjerenje vibracija, nadzor graničnih vrijednosti ovisno o pogonskom režimu, automatizirana dijagnostika.	od 1985

Ciljevi održavanja po stanju općenito

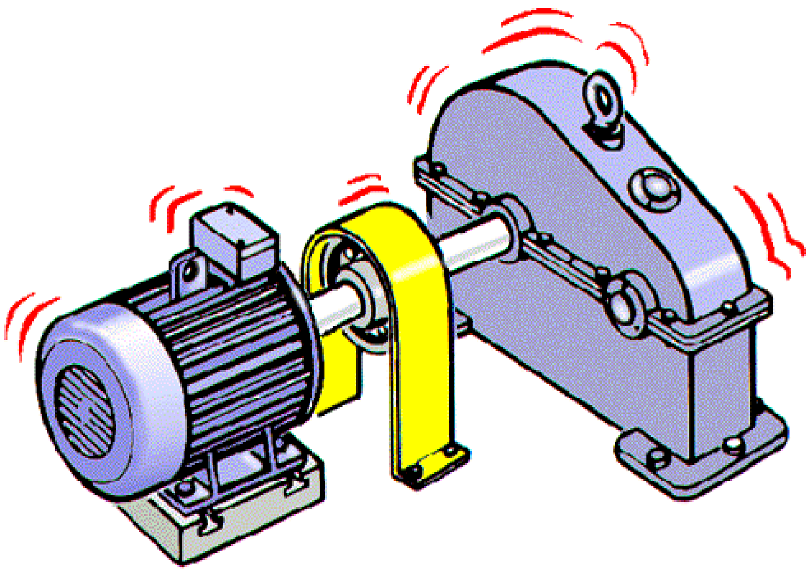
- Povećanje sigurnosti pogona
- Smanjenje troškova održavanja
- Produljenje vijeka trajanja postrojenja
- Povećanje raspoloživosti pogona

Definicije

- **Vibracija** je oscilacija čiji je iznos parametar koji definira gibanje sustava.

- **Oscilacija** je promjena intenziteta neke veličine u odnosu na zadanu referentnu vrijednost, pri čemu se intenzitet naizmjenično mijenja iznad ili ispod referentne vrijednosti.

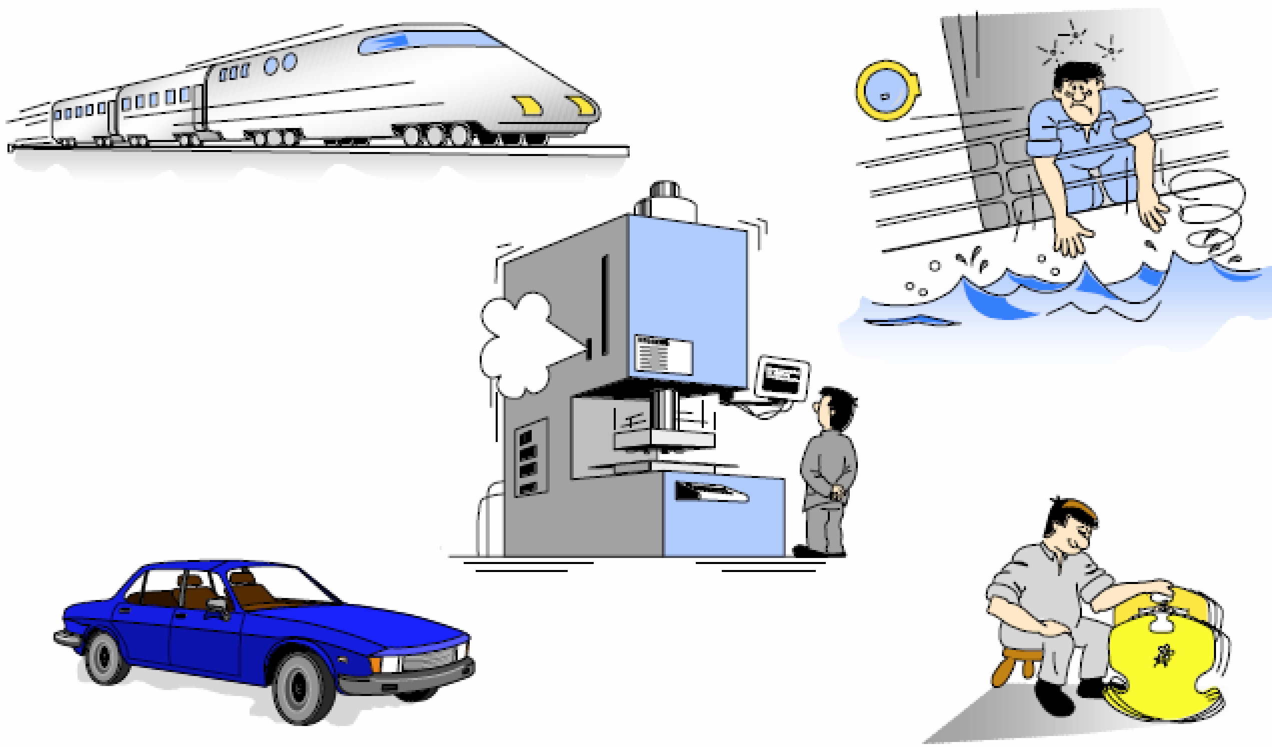
Haris: "Shock and Vibration Handbook"



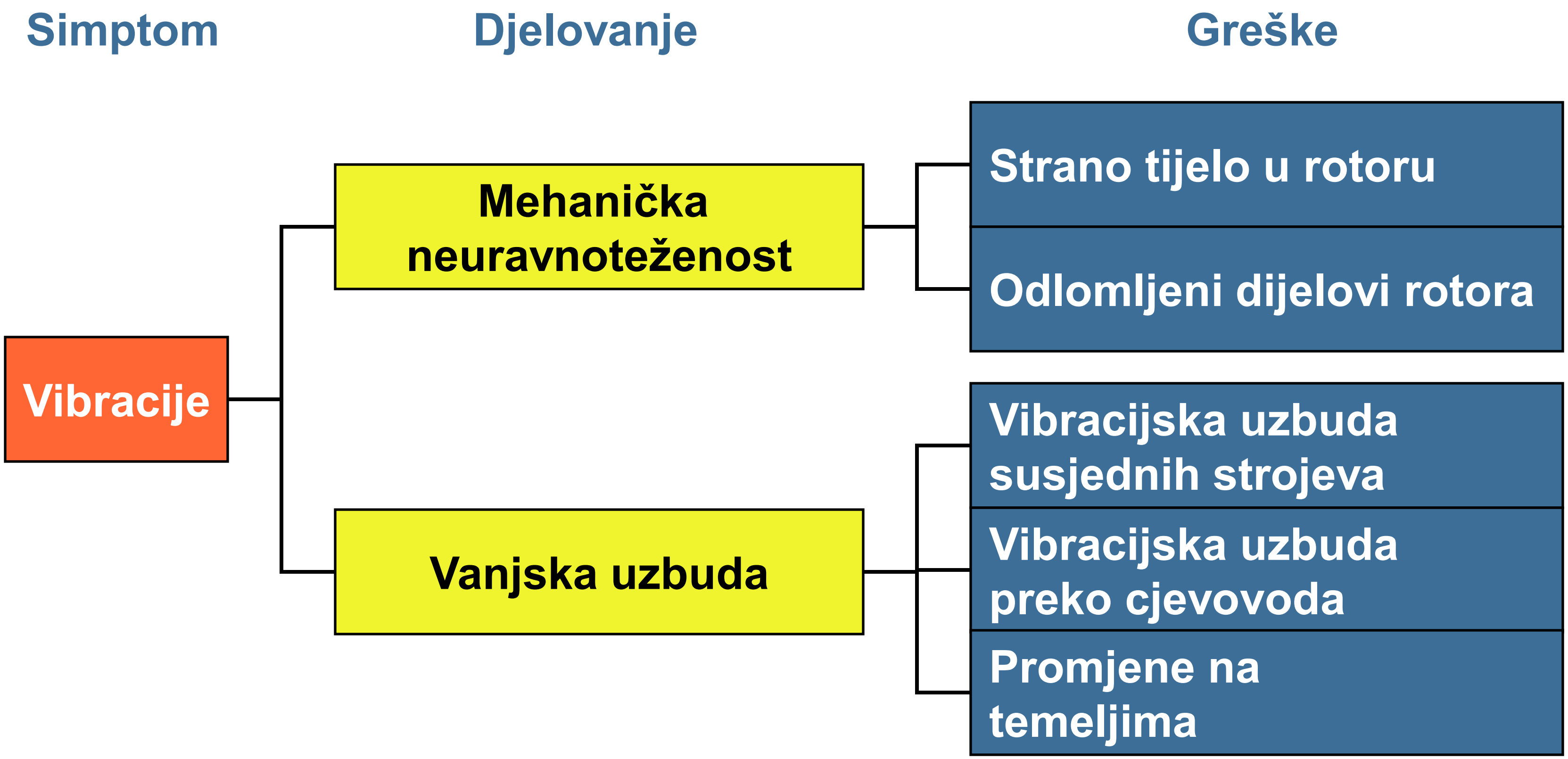
Svako gibanje koje se ponavlja u nekom vremenskom intervalu zove se ***vibracija*** ili ***oscilacija***.

Posljedice vibracija

Primjeri vibracija u svakodnevnom životu



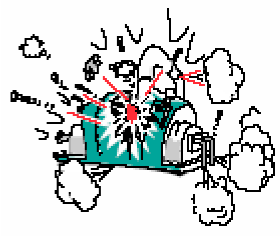
Vibracije kao indikatori stanja stroja



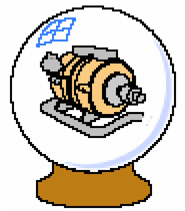
Simptom – **Djelovanje** – **Greške**

- **Vibracije**
  - **Hidraulička neuravnoteženost**
    - Kavitacija
    - Pumpa nije cjelovito odzračena
  - **Trošenje**
    - Trošenje prstenastih raspora
    - Trošenje ležaja
  - **Struganje rotora uslijed toplinskog izvitoperenja**
    - Savijanje osovine
    - Savijanje kućišta

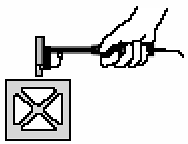
Zašto mjeriti vibracije?



- Zbog provjere frekvencija i amplituda naprezanja kako se nebi prešla dinamička izdržljivost materijala (Wöhlerova krivulja)
- Zbog izbjegavanja pobude rezonancije određenih dijelova strojeva



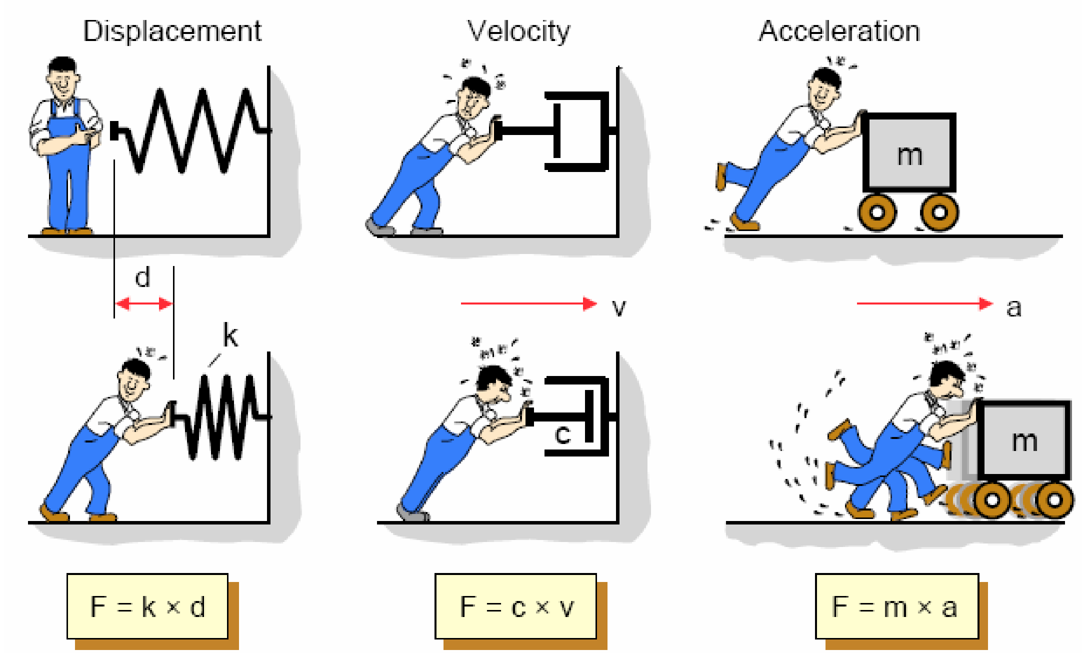
- Zbog potrebe prigušenja i izolacije izvora vibracija
- Zbog uvođenja sustava održavanja po stanju



- Zbog konstrukcije i verifikacije računalnih modela struktura

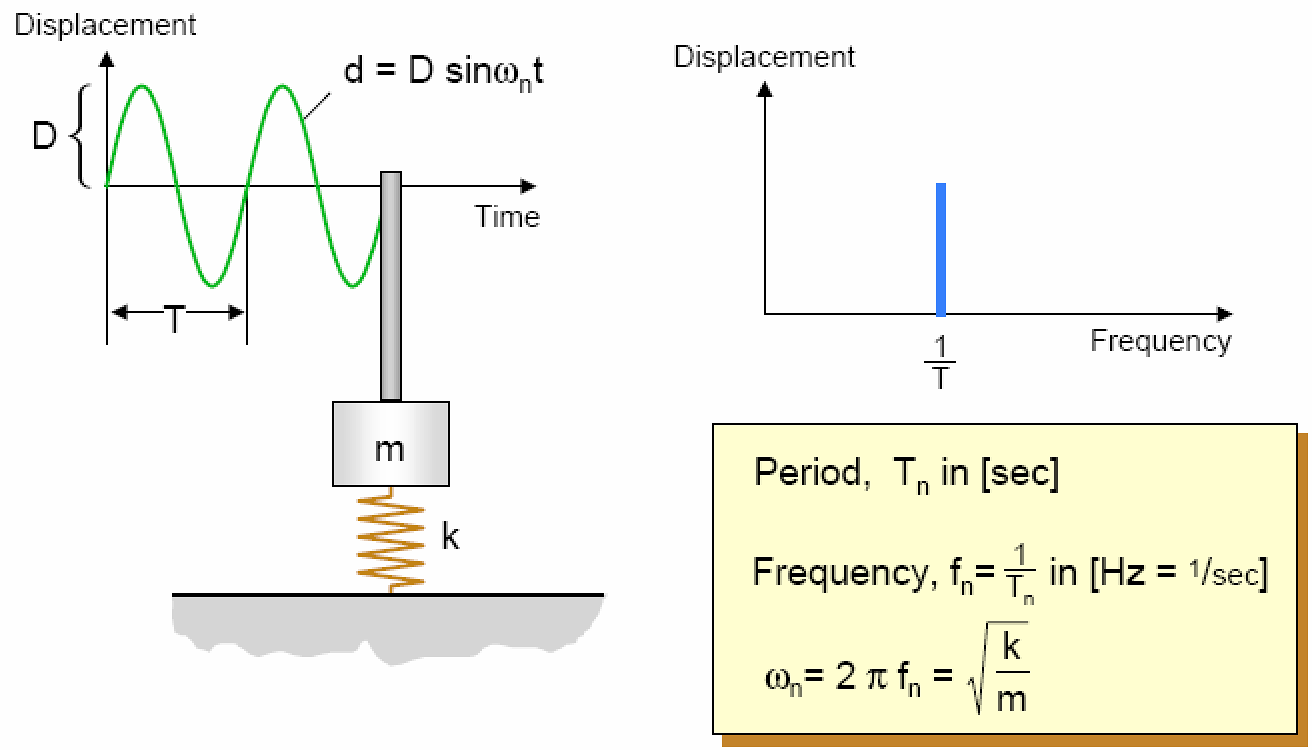
Mehanički parametri

- Mehanički sustavi sadrže tri komponente:
  - oprugu
  - prigušenje
  - masu
- Kad se svaka od tih komponenti izloži djelovanju konstantne sile, one reagiraju konstantnim **pomakom** **(d)**, konstantnom **brzinom** **(v)** i konstantnim **ubrzanjem** **(a)**

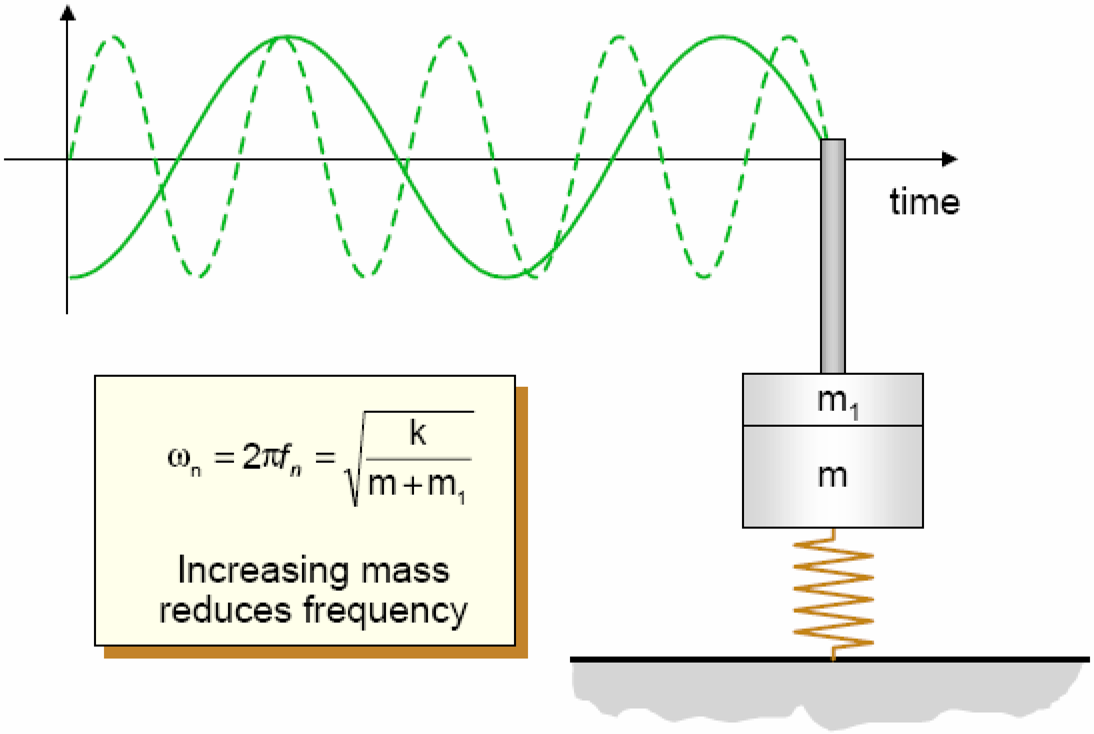


Primjeri vibracijskih sustava

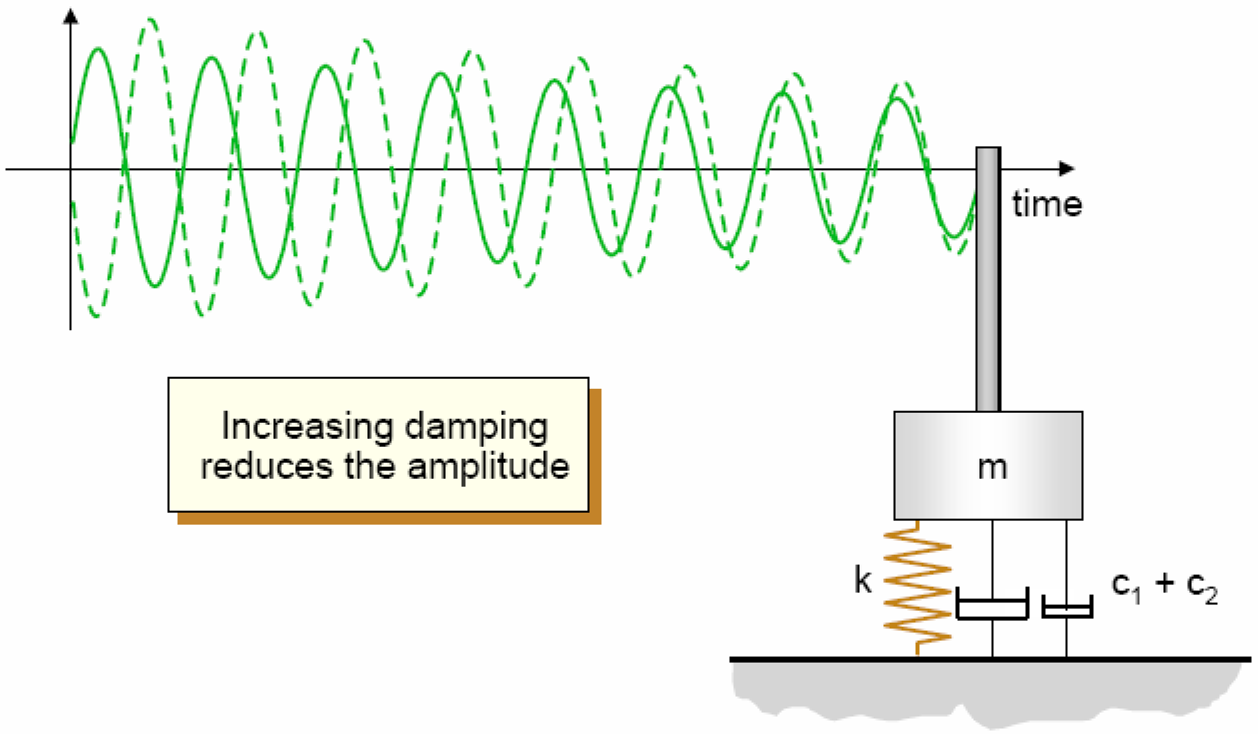
1. Sustav masa - opruga



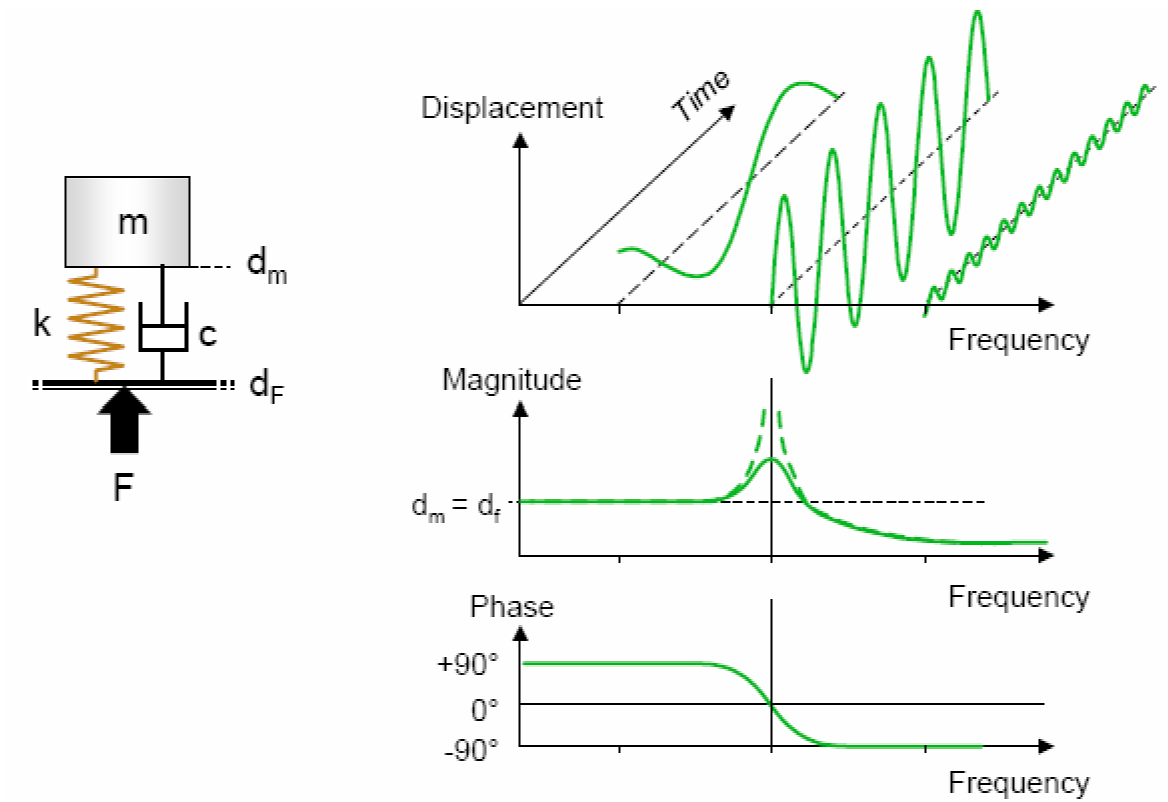
2. Sustav dvije različite mase - opruga



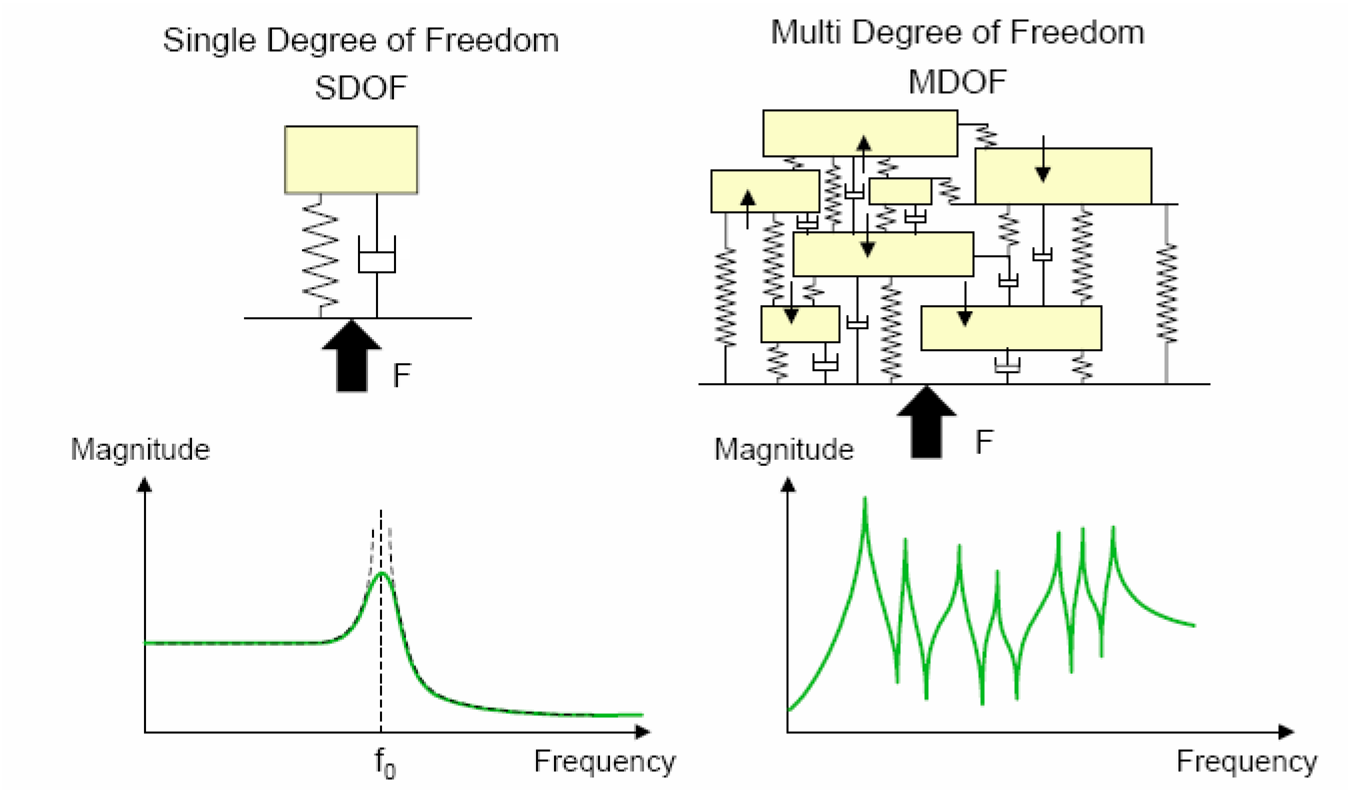
3. Sustav masa – opruga - prigušivač



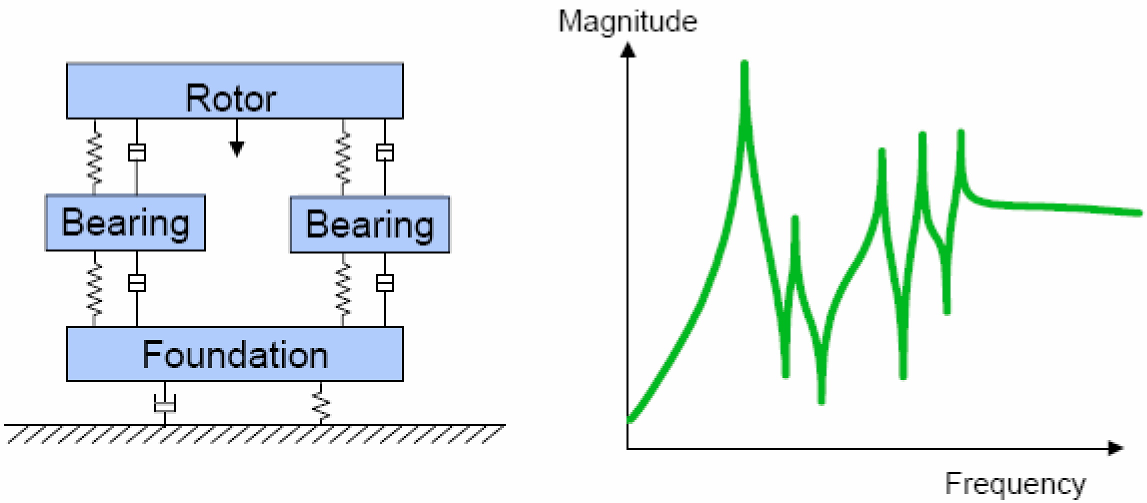
4. Sustav masa – opruga – prigušivač - sila



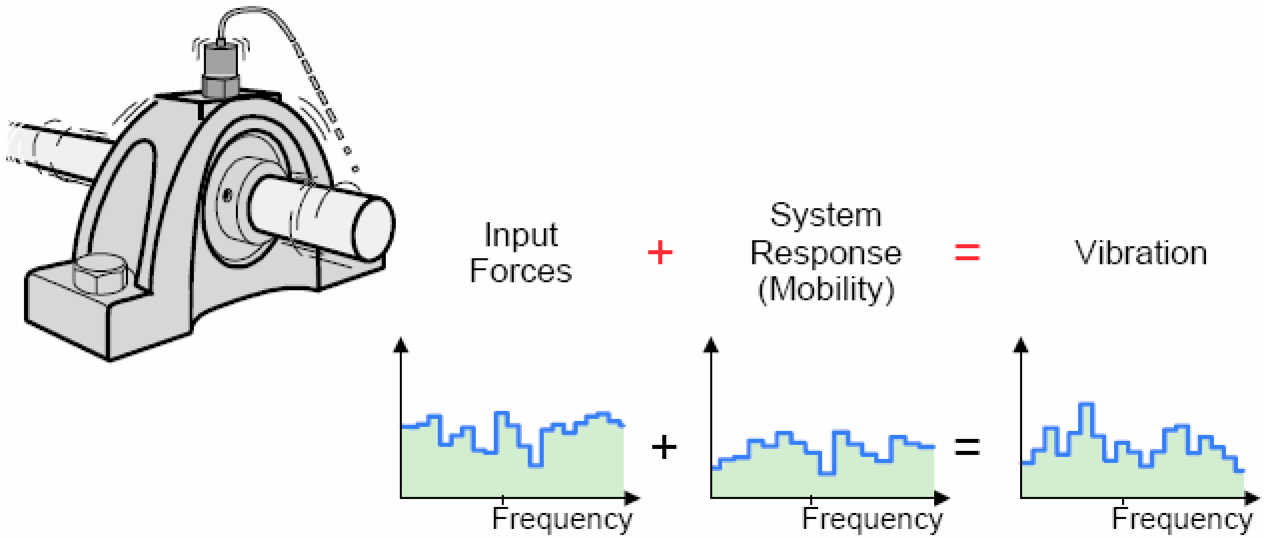
Odzivi teorijskih sustava



Odzivi "stvarnih" sustava



Sile i vibracije

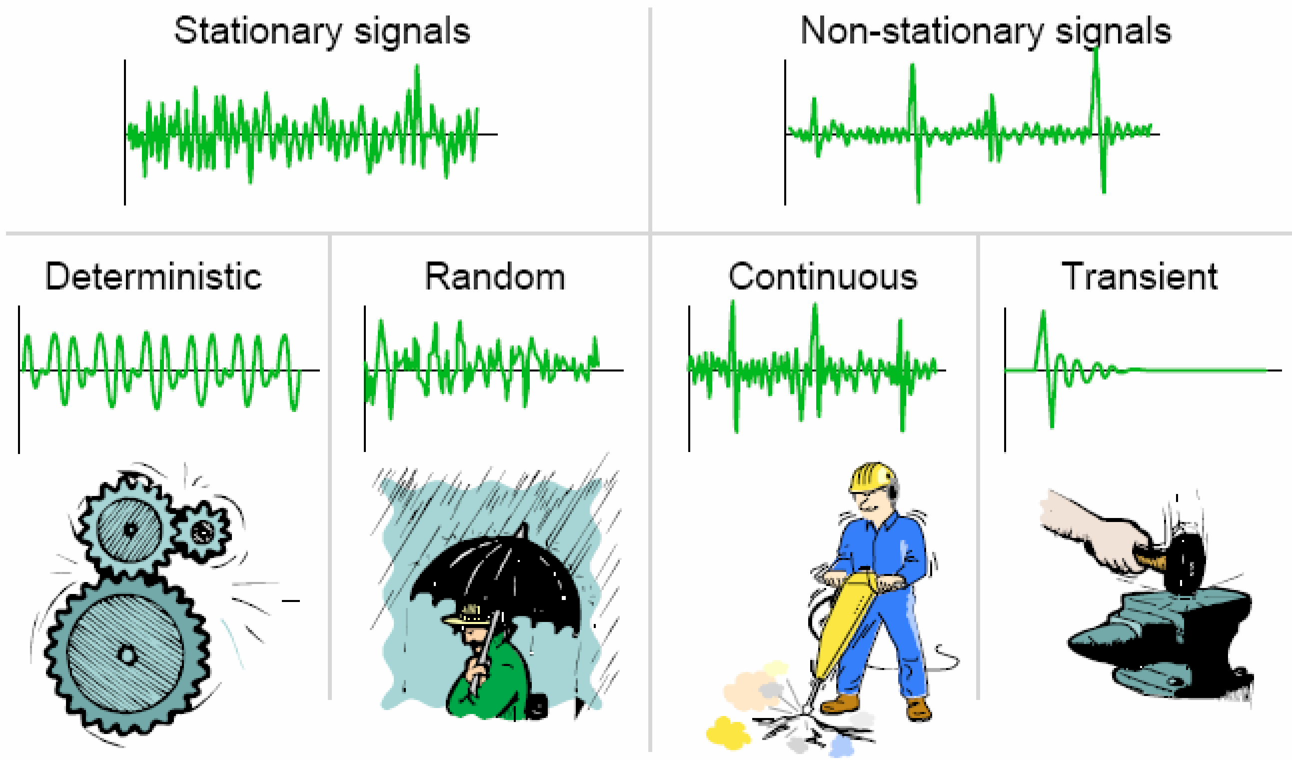


Forces caused by
- Imbalance
- Shock
- Friction
- Acoustic

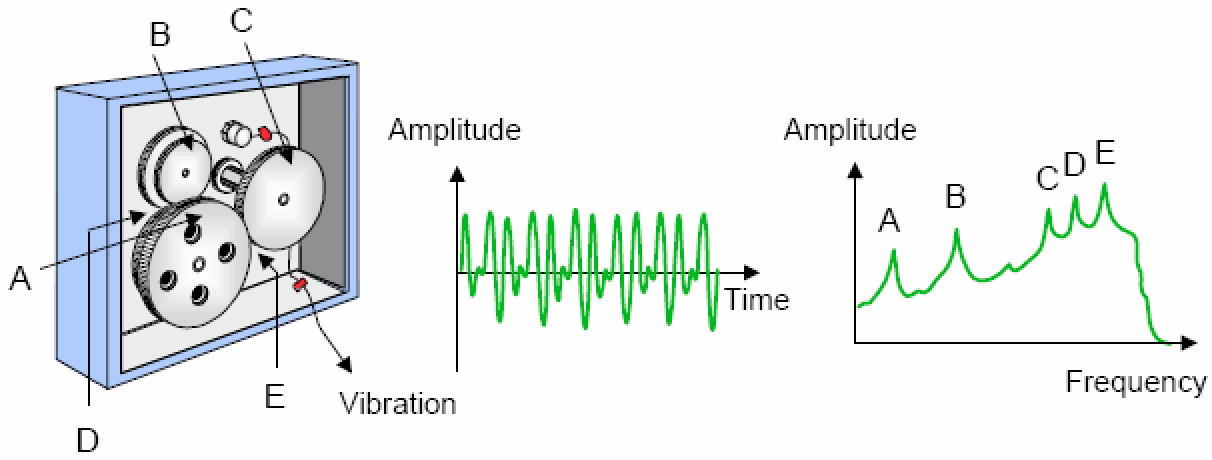
Structural Parameters:
- Mass
- Stiffness
- Damping

Vibration Parameters:
- Acceleration
- Velocity
- Displacement

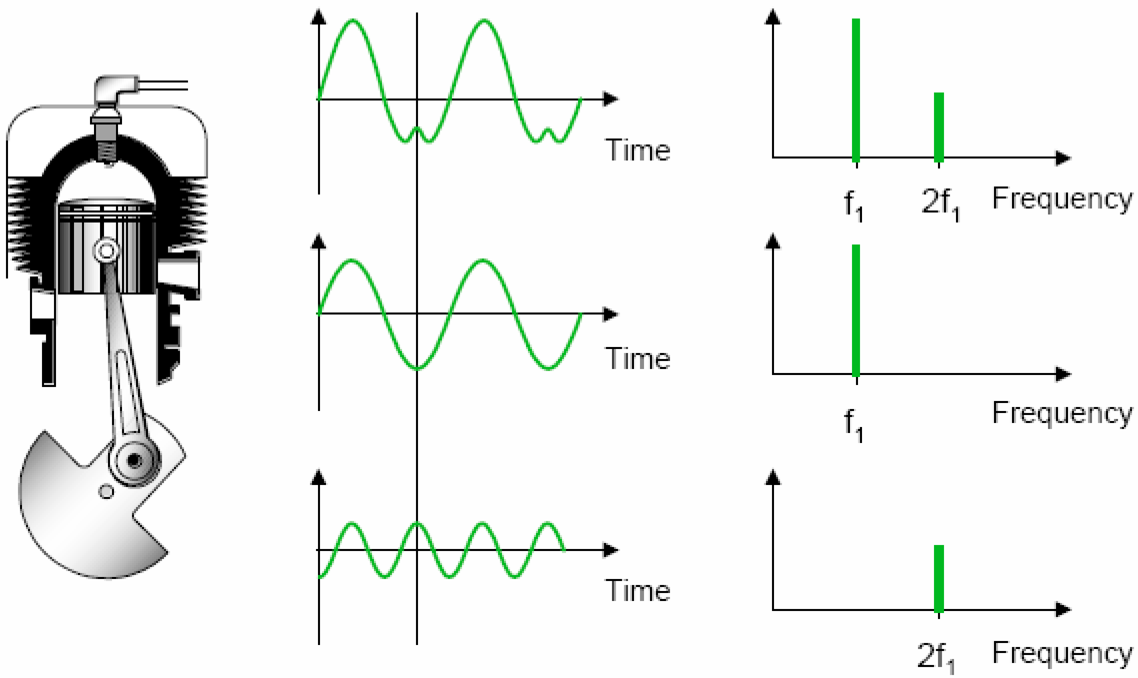
Vrste vibracijskih signala



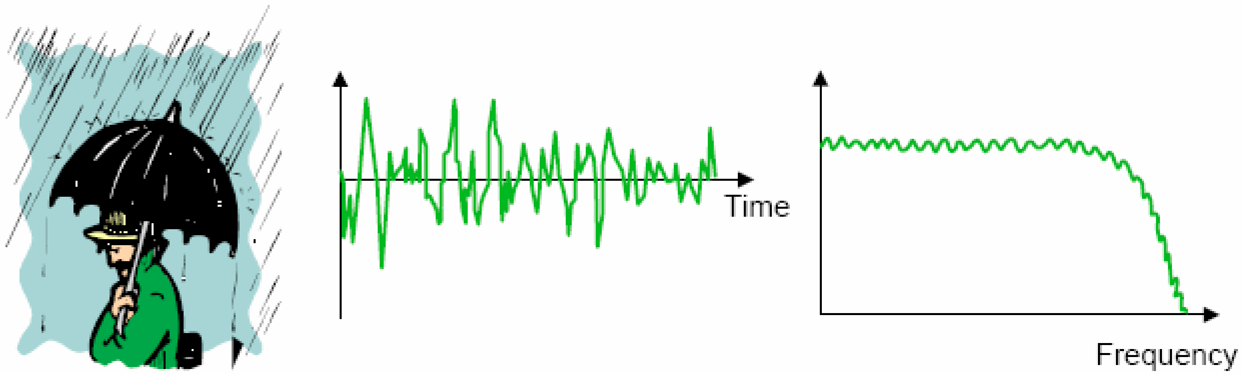
Deterministički vibracijski signali



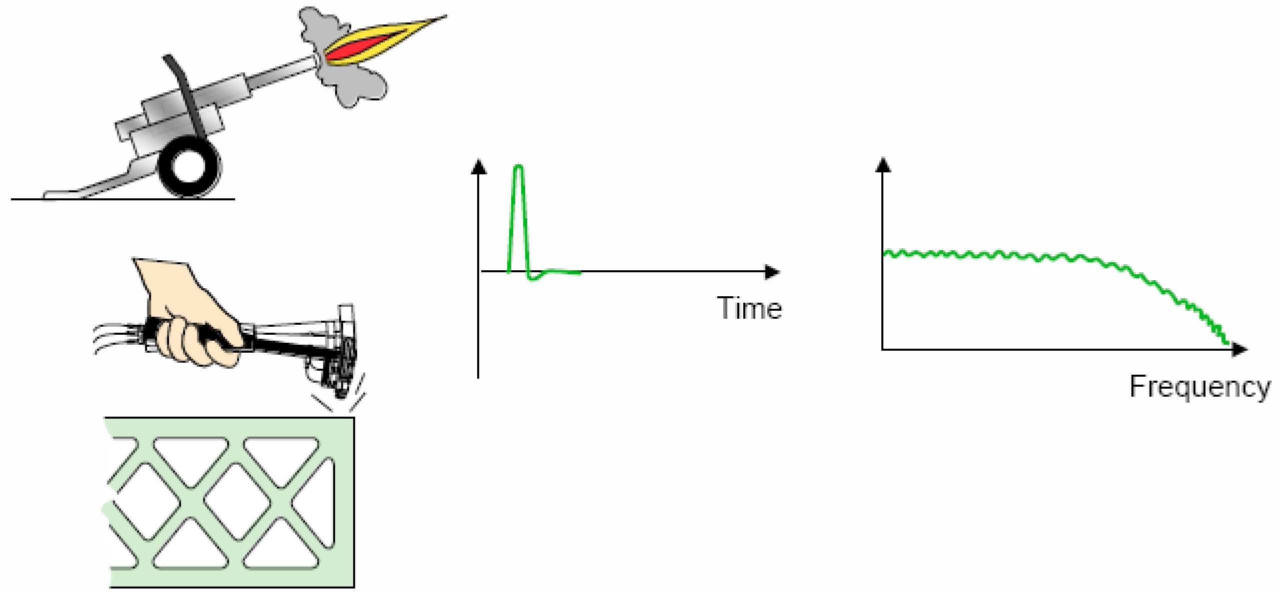
- **Deterministički vibracijski signali i harmonici**



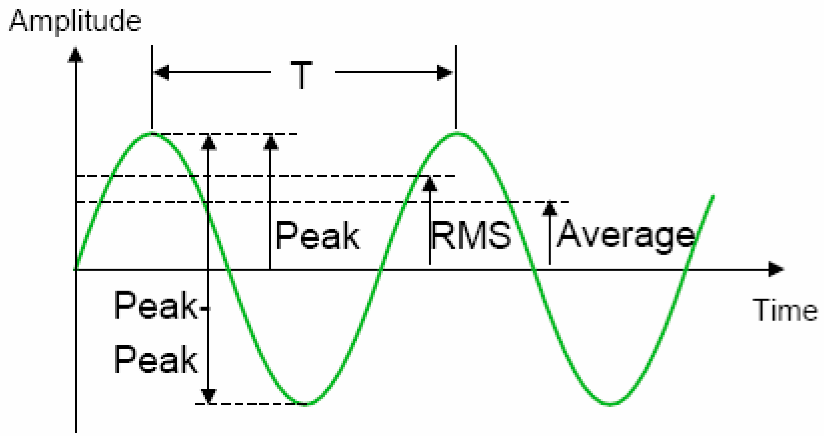
- **Slučajni (Random) vibracijski signali**



- **Udarno – Impulsni vibracijski signali**



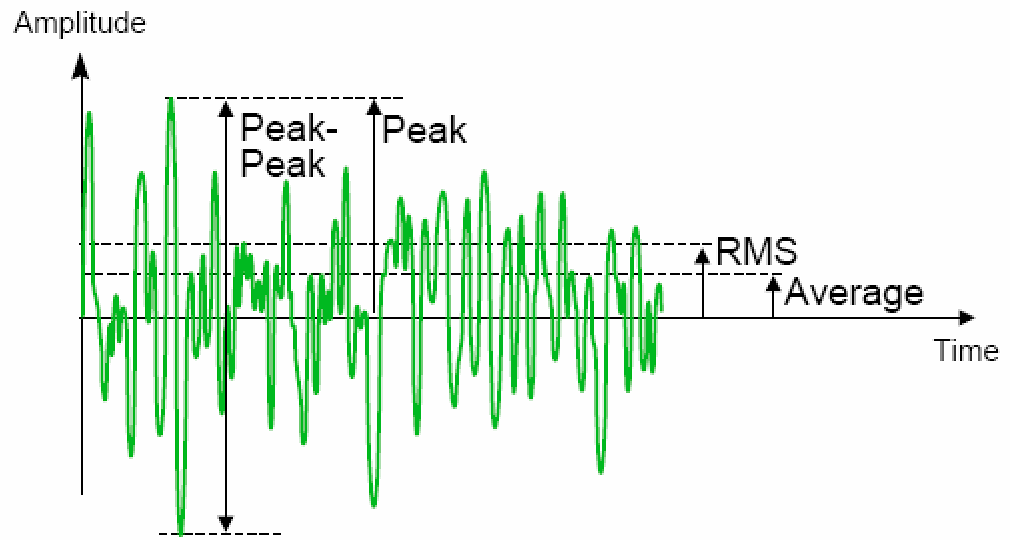
Načini mjerenja vibracijskih signala



$$\text{RMS} = \sqrt{\frac{1}{T}\int_0^T x^2(t)\,dt}$$

$$\text{Average} = \frac{1}{T}\int_0^T |x(t)|\,dt$$

$$\text{Crest Factor} : \frac{\text{Peak}}{\text{RMS}}$$



$$\text{RMS} = \sqrt{\frac{1}{T}\int_0^T x^2(t)\,dt}$$

$$\text{Average} = \frac{1}{T}\int_0^T |x(t)|\,dt$$

$$\text{Crest Factor}: \frac{\text{Peak}}{\text{RMS}}$$

Jedinice mjerenja vibracijskih signala

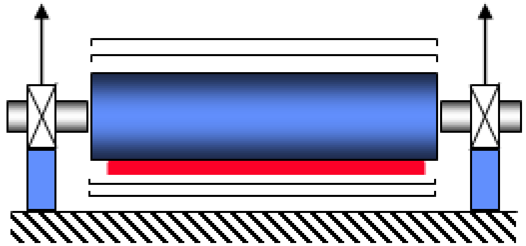
Acceleration a	1ms^{-2} (m/s^2)	= 0.102g = 39.4 in/s^2
Velocity v	1ms^{-1} (m/s)	= 3.6 km/h = 39.4 in/s
Displacement d	1m	= 1000 mm = 39.4 in

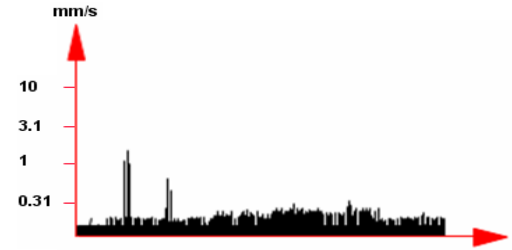
$$1g \equiv 9.80665\ ms^{-2}$$

Analiza uzroka vibracija

- Neravnoteža sustava
- Asimetričnost sustava
- Savijanje osovine/vratila
- Ekscentričnost
- Ležajevi

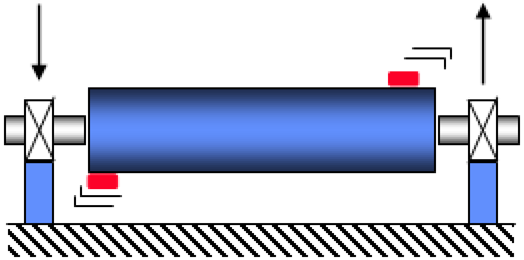
Neravnoteža





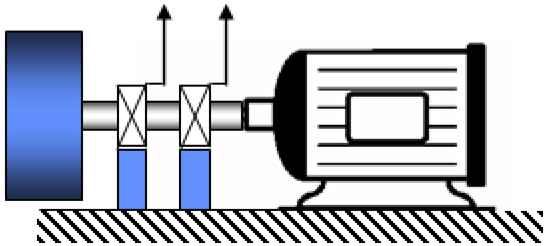
Statička neravnoteža

- Jednak fazni pomak na svaki od ležajeva
- Uglavnom radijalne vibracije



Dinamička neravnoteža

- Fazni pomak od 180°
- Uglavnom radijalne vibracije

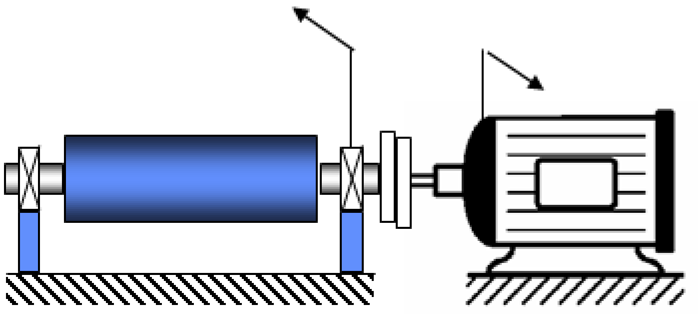


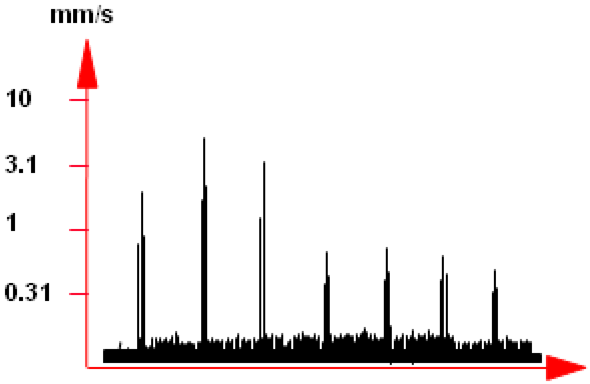
Neravnoteža konzolnog opterećenja

- Istovremene radijalne i aksijalne vibracije
- Statička i dinamička neravnoteža

Asimetričnost

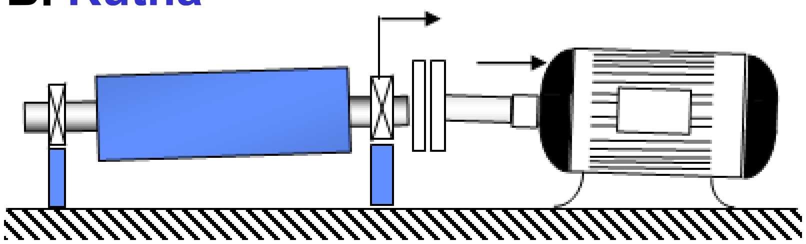
A. Paralelna

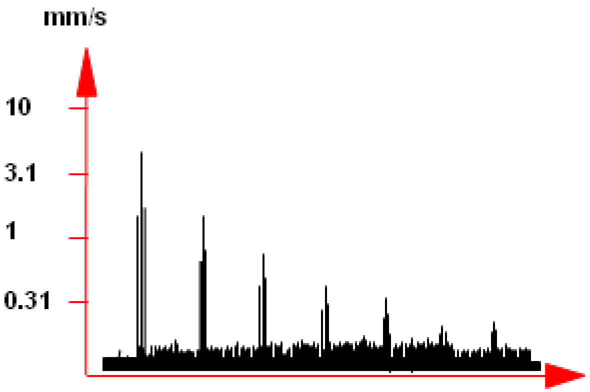




- Radijalne vibracije sa faznim pomakom od 180°

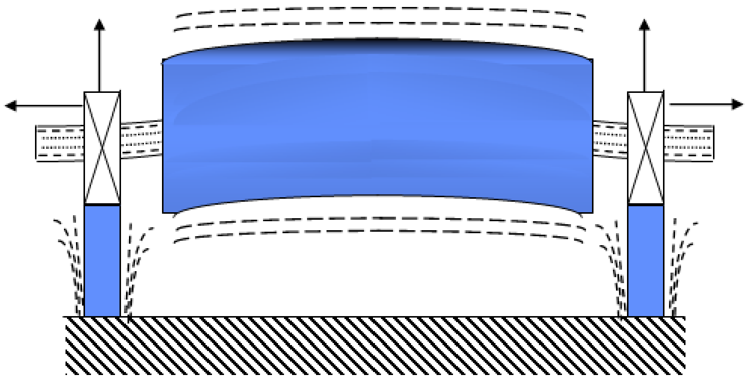
B. Kutna

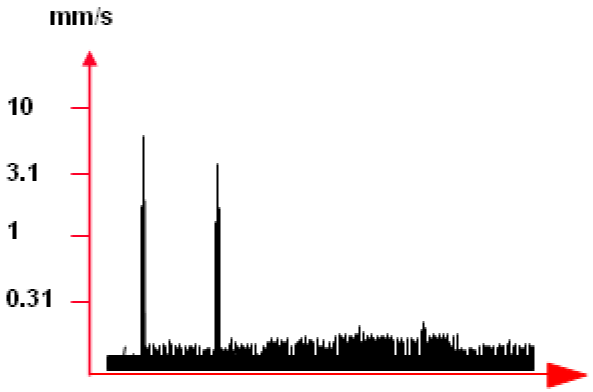




- Aksijalne vibracije sa faznim pomakom od 0°

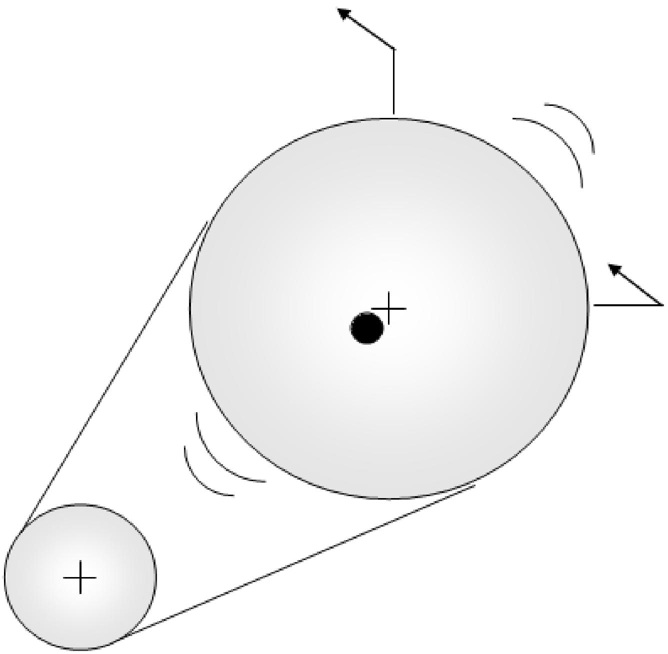
Savijanje osovine

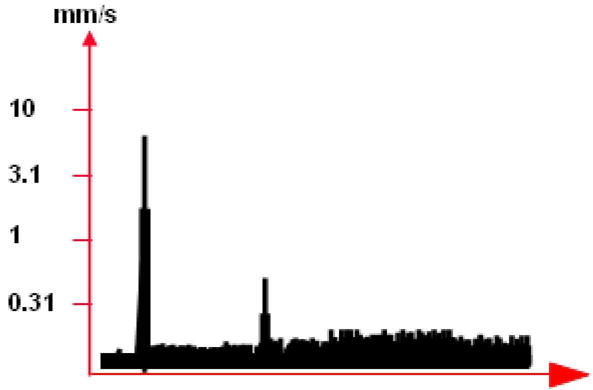




- Aksijalne i radijalne vibracije
- 180° fazni pomak kod aksijalnih vibracija
- 0° fazni pomak kod radijalnih vibracija

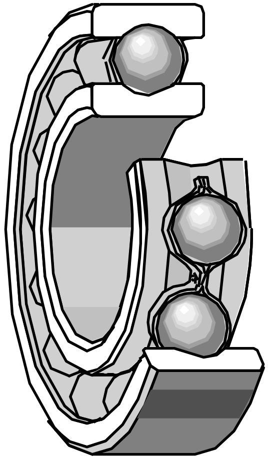
Ekscentričnost



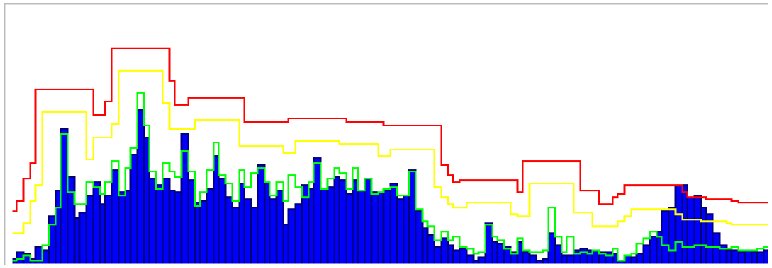


- Centar rotacije različit od geometrijskog centra
- Radijalna i aksijalna faza jednake ili različite od 180°

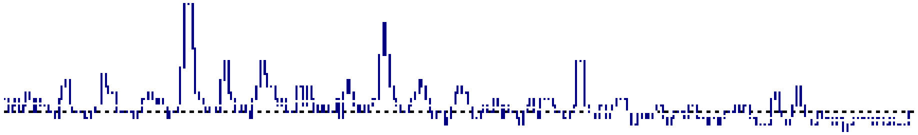
Vibracije kotrljajućih ležajeva



- Greške kotrljajućih ležajeva detektiraju se pomoću CPB metode u visokofrekvencijskom opsegu

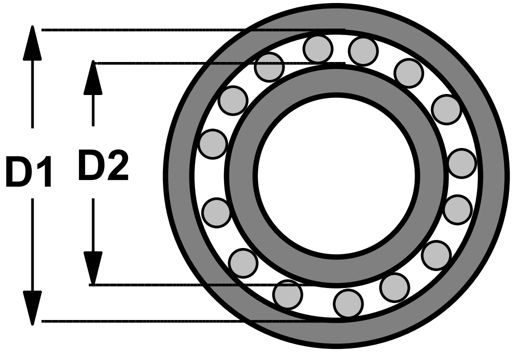


- Primjena "Envelope spectra" metode za detekciju i dijagnozu stanja ležaja



- U slučaju da grešaka nema dobiva se tzv. "flat envelope" spektar

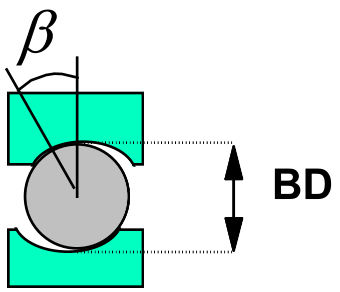
Izračunavanje frekvencija elemenata ležajeva



$$PD = \frac{D1 + D2}{2}$$

n = broj kuglica

f_r = frekvencija rotacije

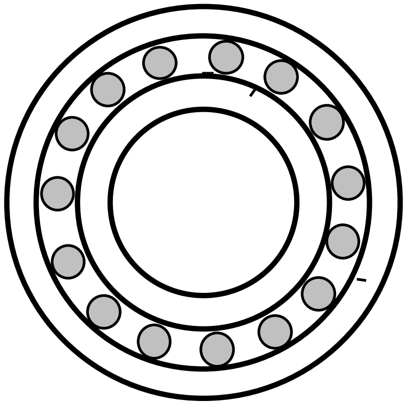


$$\text{BPFO} = f_{outer}(Hz) = \frac{n}{2} f_r \left(1 - \frac{BD}{PD}\cos\beta\right)$$

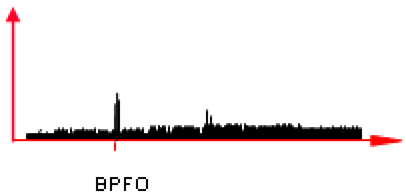
$$\text{BPFI} = f_{inner}(Hz) = \frac{n}{2} f_r \left(1 + \frac{BD}{PD}\cos\beta\right)$$

$$\text{BSF} = f_{ball}(Hz) = f_r \frac{PD}{BD}\left[1 - \left(\frac{BD}{PD}\cos\beta\right)^2\right]$$

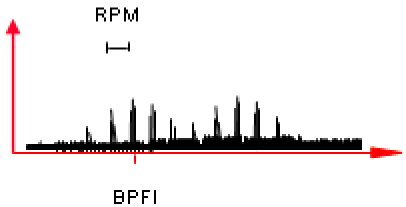
$$f_{cage}(Hz) = \frac{1}{2} f_r \left(1 - \frac{BD}{PD}\cos\beta\right)$$



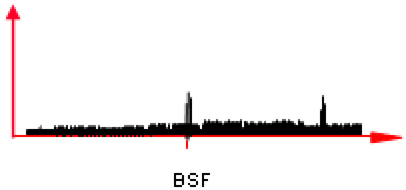
1. Greške vanjske staze kotrljanja
- *Ball Pass Frequency Outer Race* (**BPFO**)
- Traje mjesecima



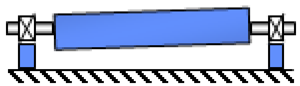
2. Greške unutarnje staze kotrljanja
- *Ball Pass Frequency Inner Race* (**BPFI**)
- Traje danima ili tjednima



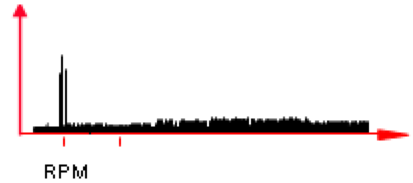
3. Greške kuglica
- *Ball Spin frequency* (**BSF**)
- Često u kombinaciji sa BPFO i BPFI
- Zahtijeva hitnu zamjenu ležaja

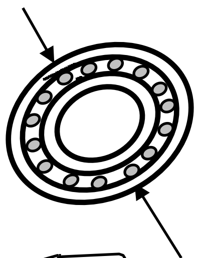


Vibracije ležajeva zbog grešaka montaže

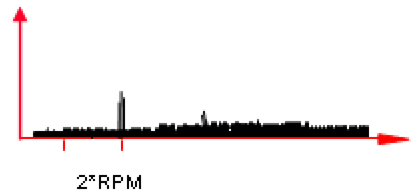


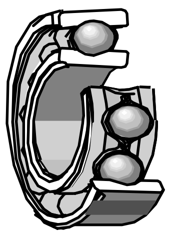
Asimetričnost rotora
Neravnoteža rotora



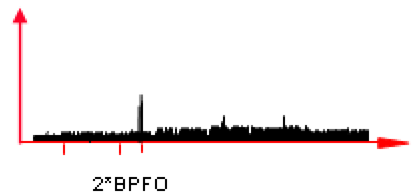


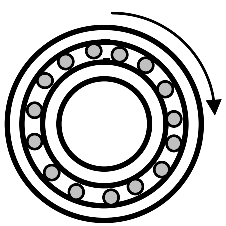
Radijalno
naprezanje ležaja



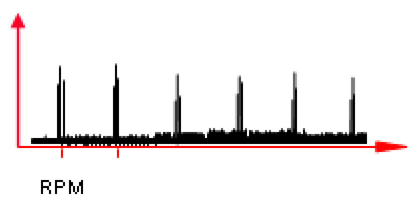


Asimetričnost
vanjske staze
kotrljanja



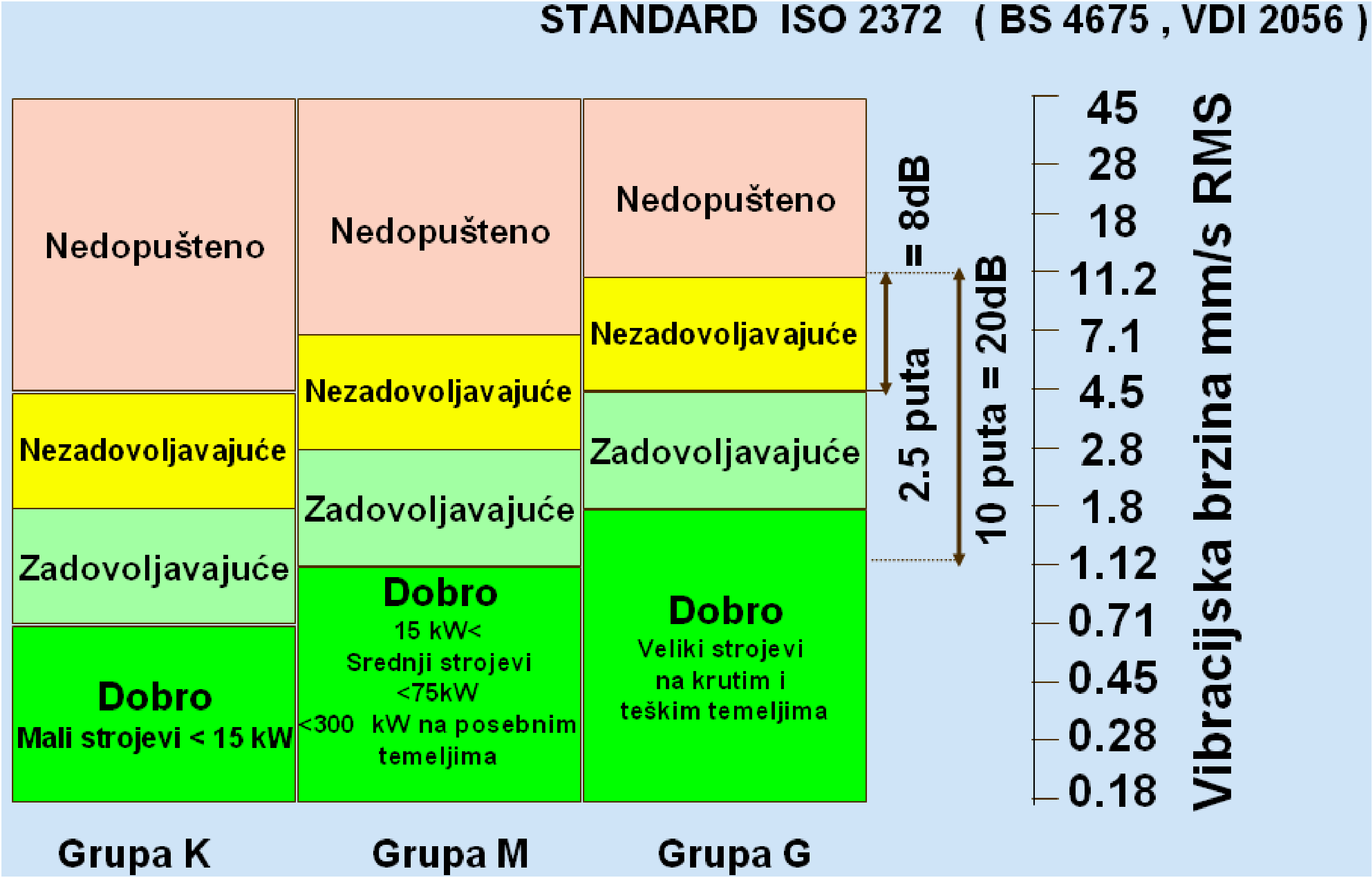


Nepravilnosti staze
zbog ugradnje
sjedišta



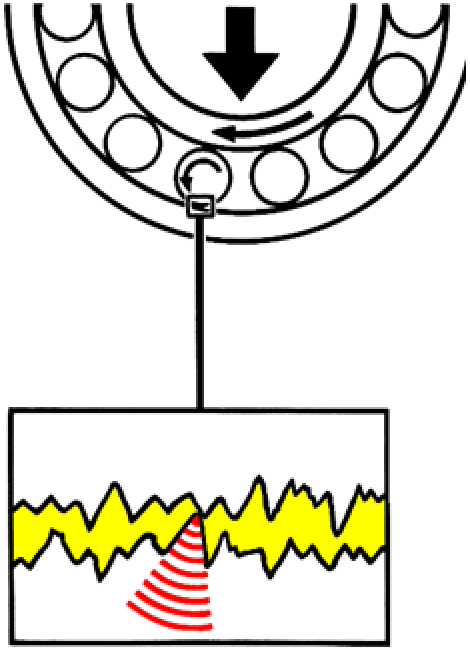
Greške podmazivanja

Procjena vibracijskog stanja sustava prema ISO 2372

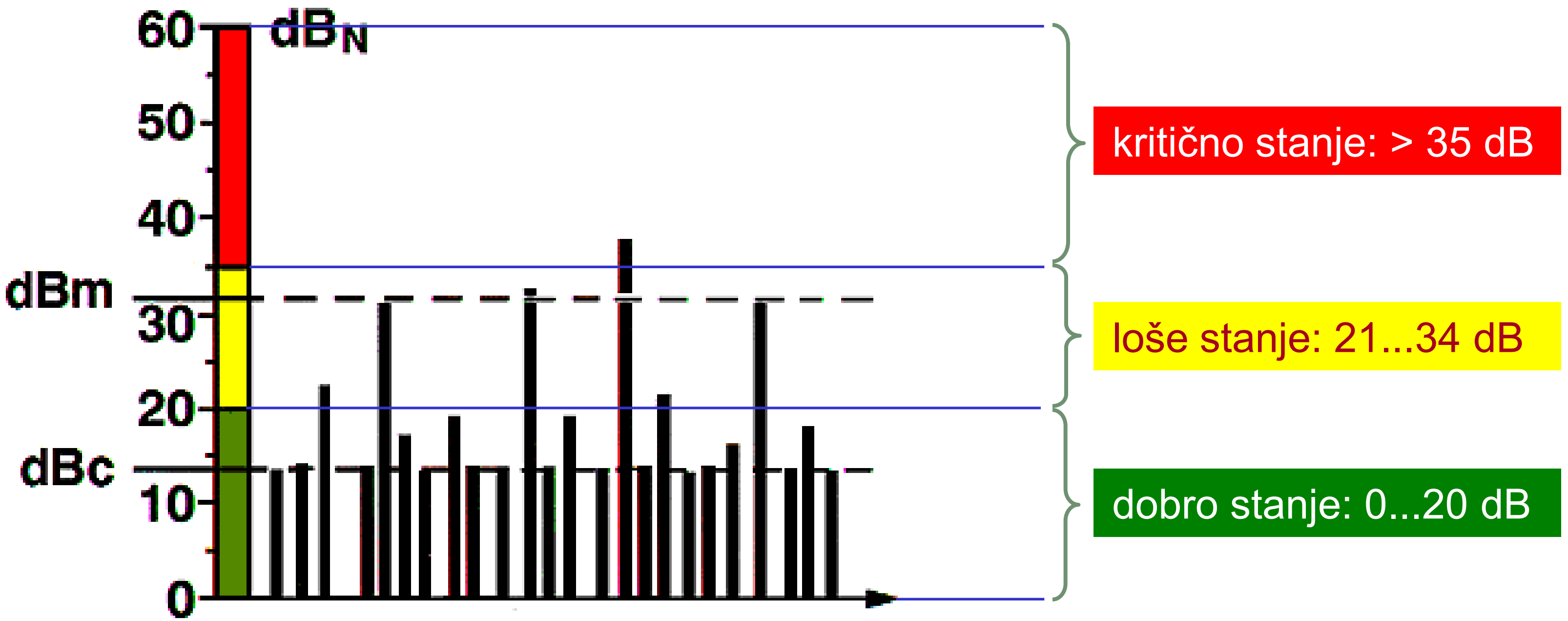


Metoda udarnih impulsa *SPM* – Shock Pulse Methods

- Švedski patent razvijen 60-tih godina
- *SPM* -om se mjere udarni valovi (impulsi) koji nastaju zbog prolaza kotrljajućeg elementa ležaja preko oštećenja

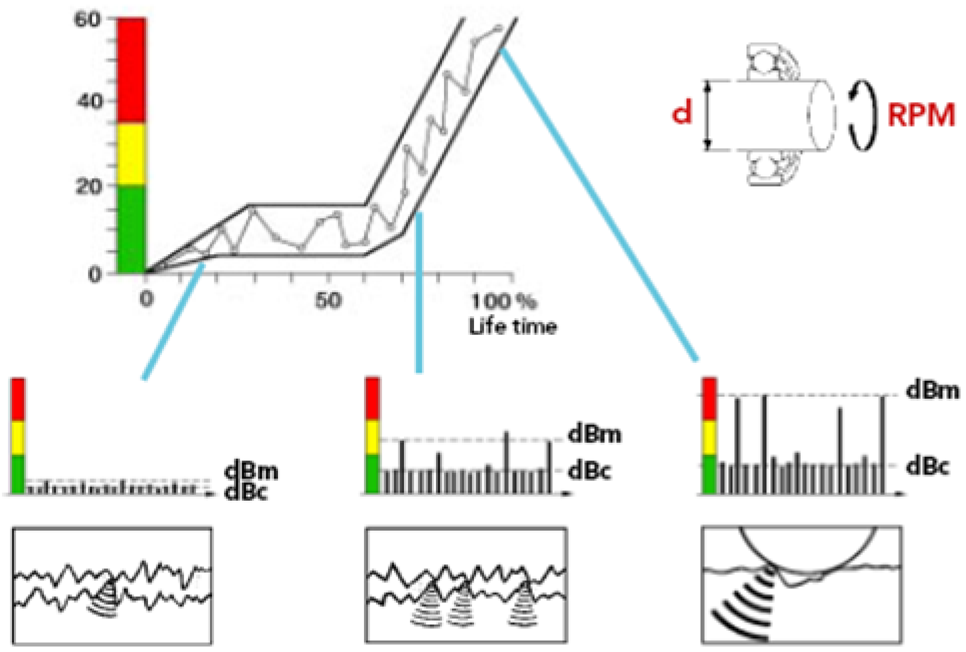


Procjena vibracijskog stanja sustava kod *SPM* metode



- **dBm** – *decibel maximum value* – maksimalna vrijednost udarnog impulsa u mjerenom signalu u dB.
- **dBc** – *decibel carpet value* – "tepih" vrijednost udarnih impulsa u mjerenom signalu u dB.
- **dB_N** – *normalized shock value* – normirana vrijednost udarnih impulsa u dB.

Propagacija oštećenja ležaja tijekom životnog vijeka



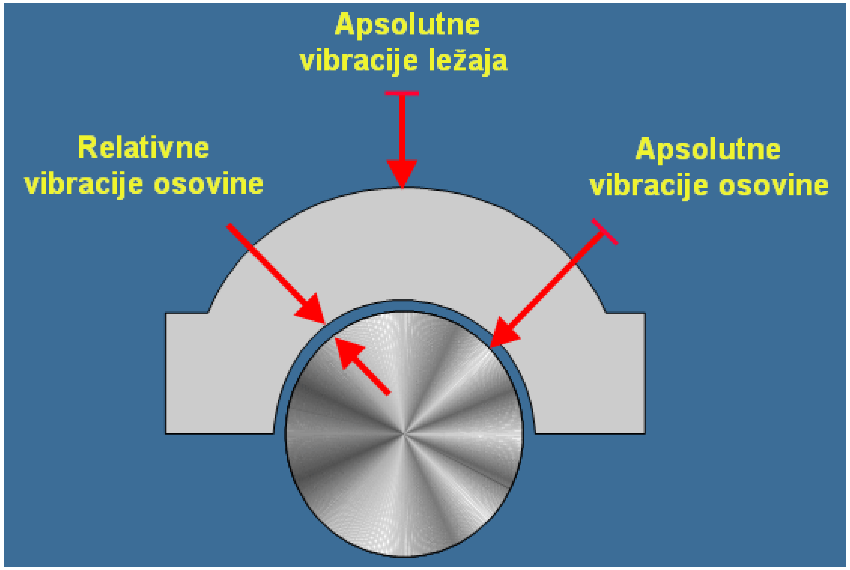
dBm vrijednosti:

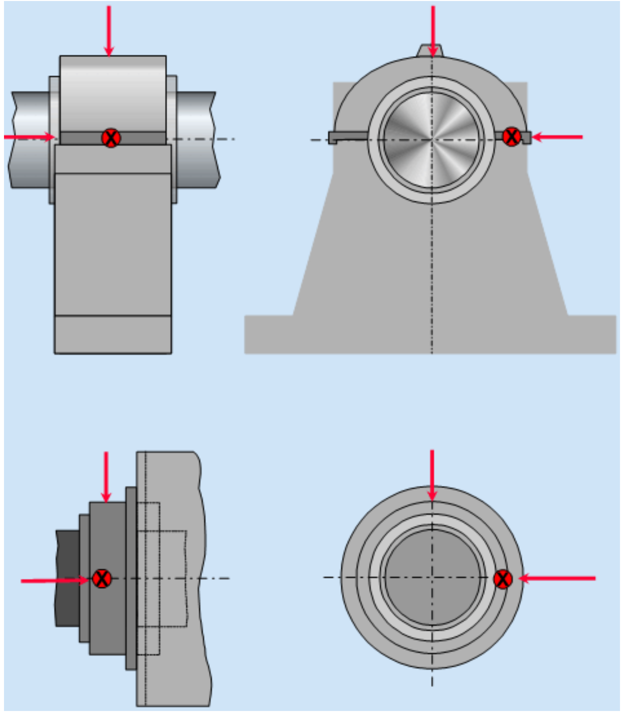
- 30...40 – **blago** oštećenje ležaja
- 40...45 – **jako** oštećenje ležaja
- > 45 – **teško** oštećenje ležaja (visok rizik od otkazivanja!)

Sustav za mjerenje vibracija *VIBROTEST - 60*

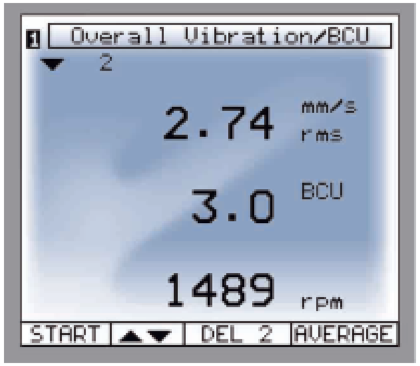
Brüel & Kjær Vibro

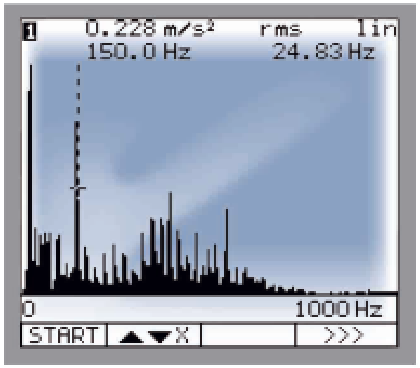
Preporuke izbora mjernih mjesta prema Brüel & Kjaer©



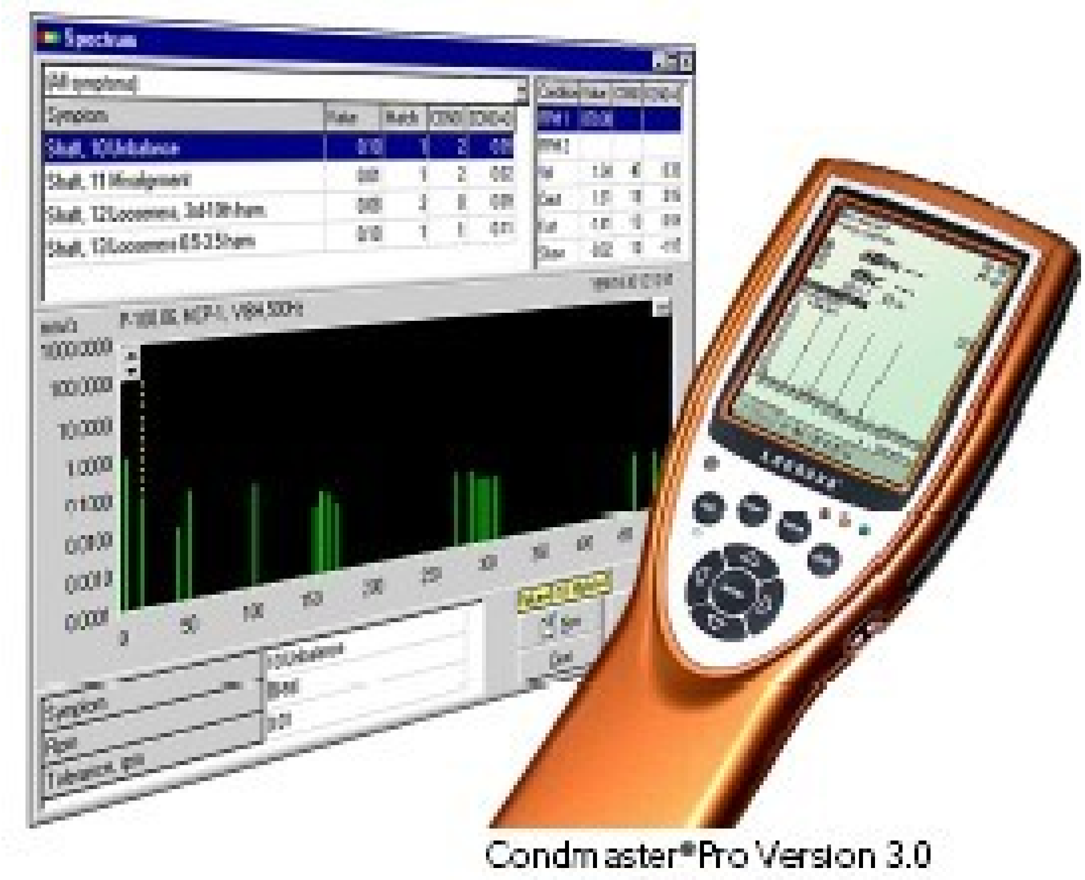


Primjer mjerenja sa *VIBROTEST- 60*



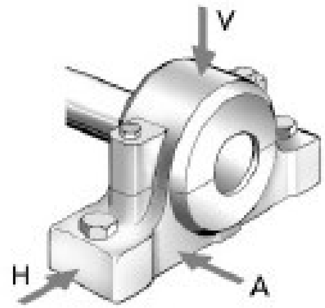


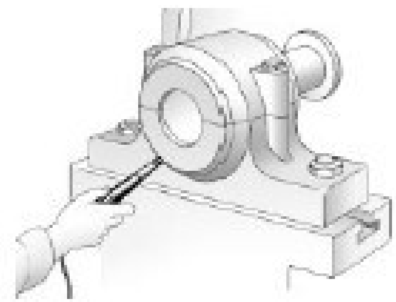
Sustav za mjerenje vibracija *SPM* - *Leonova*

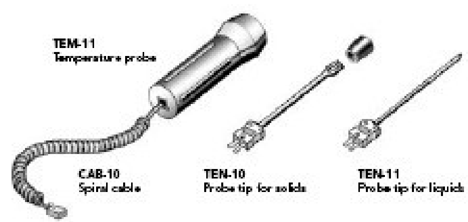


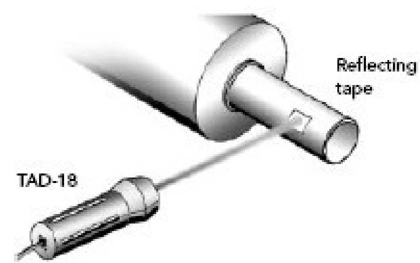
Primjeri mjerenja sustavom *SPM - Leonova*

- Mjerenje vibracija
- SPM
- Mjerenje temperature
- Mjerenje broja okretaja









Primjer prikaza rezultata mjerenja *SPM* metodom