Application of TRIZ to Noise & Vibration Problem Solving

Fusion with Traditional Approach

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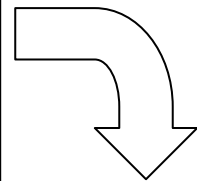# Symptoms coming from customers

Verbal Expressions
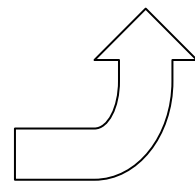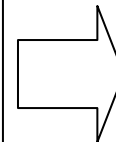Booming
Roaring
Rumbling
Quaking
Knocking
Warbling
Chirping
*****

Oral Imitations

Whooooon
Ti_Ti_Ti_Ti
Kuuuuuuu

Conversion Table

Generalized Noise and Vibration Problems

Sorted by frequency range
Low, Middle, High

Sorted by time dependency
Continuous constant
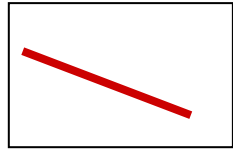Continuously varying frequency
Intermittent

Sorted by sound quality
Monotone
With harmonics
Random noise

Sorted by operating conditions
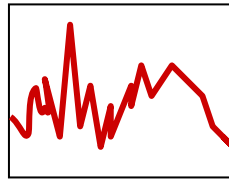Vehicle speed
Engine speed
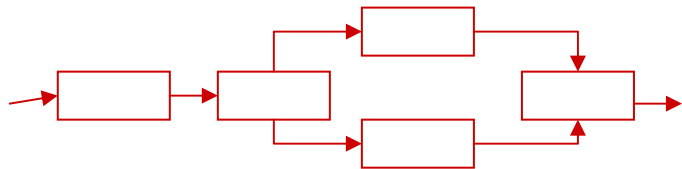Engine loading

Target Performances

Trend　　**Balance**　　**Spectrum**

Modeling of the problem

Block diagram for excitation and transmission

Method of performance prediction

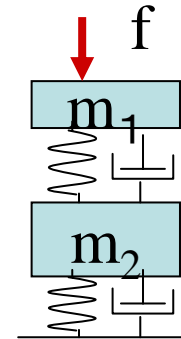Numerical simulation (mass-spring system, finite element method, etc.)

Data-based prediction

Design solutions

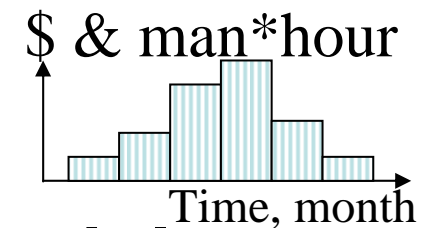Tuning of stiffness, damping or mass

Excitation force reduction

Mode tuning
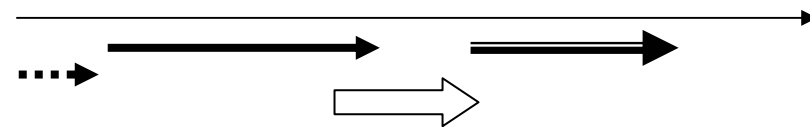

Evaluation methods

Shaker tests on parts

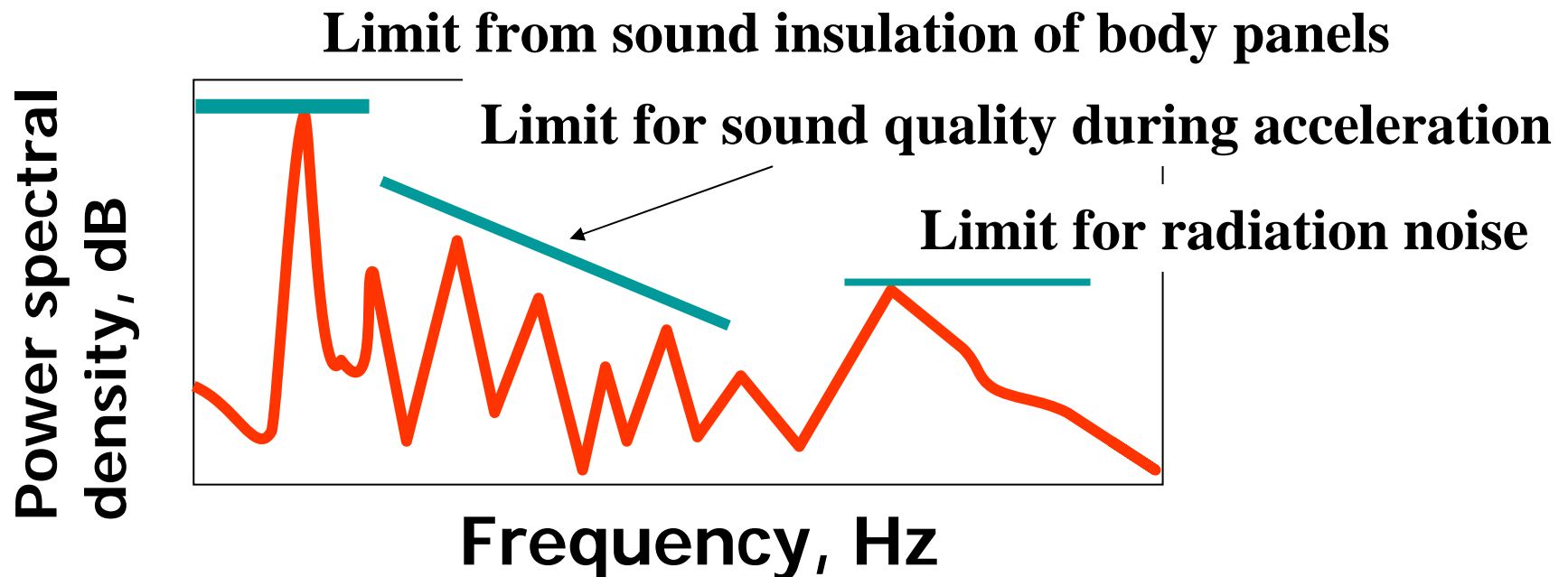Bench tests of unit prototypes

Prototype vehicle test run

Resources

Project schedule

NV Control Plan in Product Development

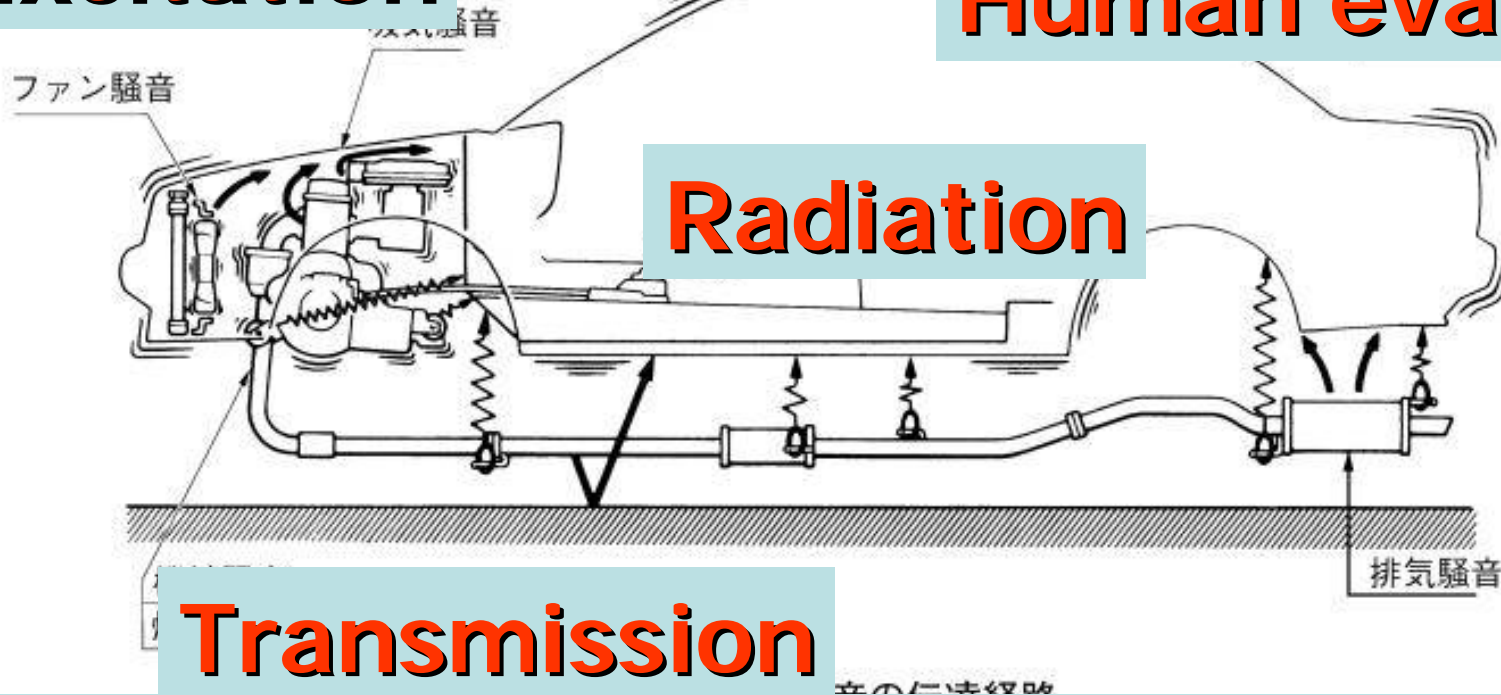# An Example of
Target Performance Description

- **Engine noise spectrum must be below the allowable limits.**
- **The limits are determined according to vehicle operating conditions.**
- **Psycho-acoustics is used.**

Limit from sound insulation of body panels

Limit for sound quality during acceleration

Limit for radiation noise

Power spectral density, dB

Frequency, Hz

Modeling of a problem

Excitation

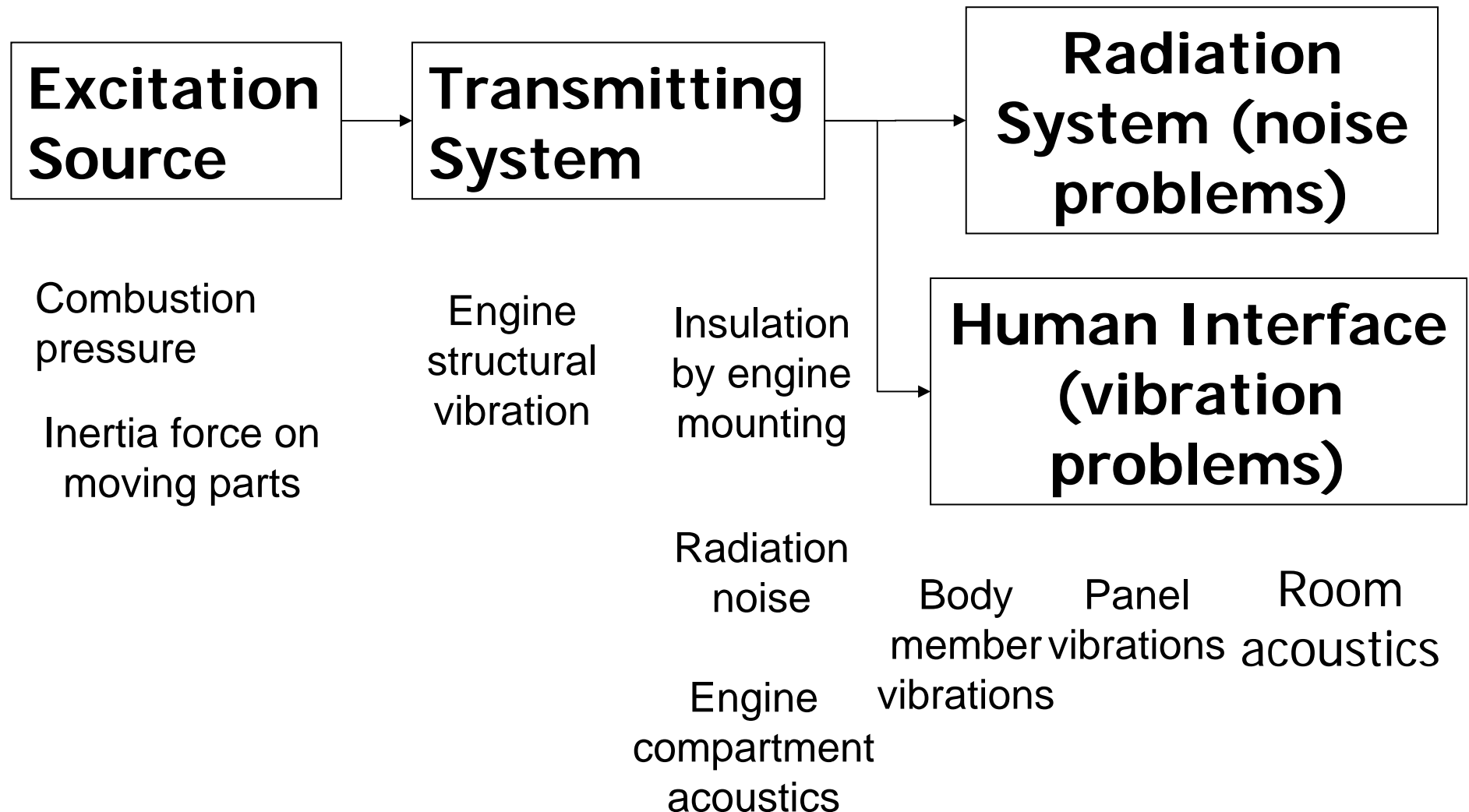**Human evaluation**

Radiation

Transmission

ファン騒音

排気騒音

- From engine vibration to engine noise heard by a passenger

An example of block diagram representation

Engine sound in a passenger compartment

| Excitation Source | → | Transmitting System | → | Radiation System (noise problems) |

Human Interface (vibration problems)

Combustion pressure

Inertia force on moving parts

Engine structural vibration

Insulation by engine mounting

Radiation noise

Engine compartment acoustics

Body member vibrations

Panel vibrations

Room acoustics

Trial of applying orthodox TRIZ method to solve NVH problems

- **Tried to use contradiction matrix approach.**
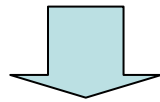
Problem definition

Technical contradiction

Inventive principles

These phase was very difficult
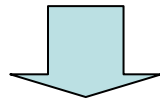
Engineering solutions
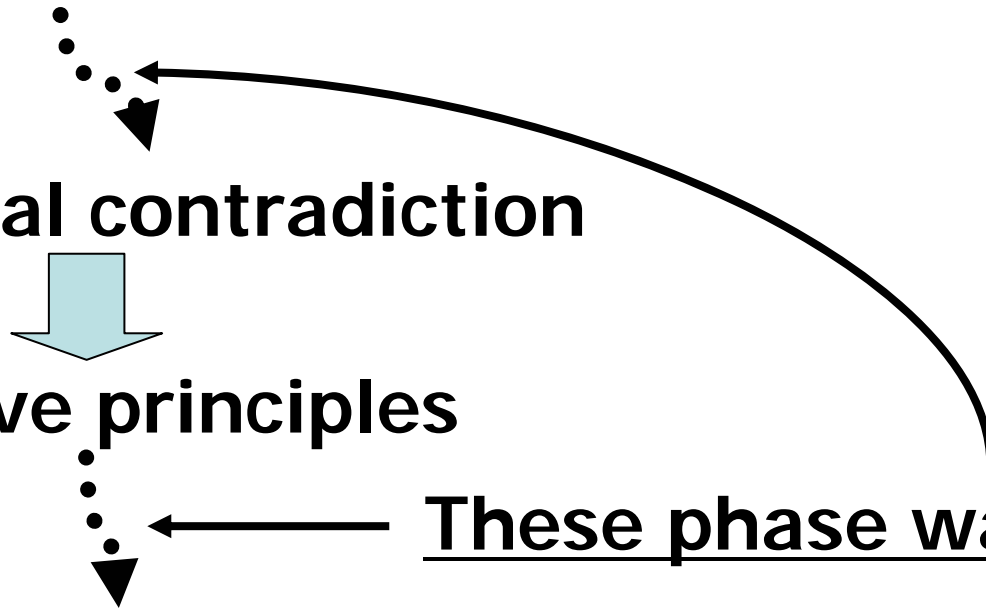
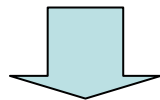# Modification of TRIZ idea to NVH problems

Problem definition categorized according to NVH symptoms

⬇

Generalized problem defined with transmission function

⬇

General solutions in NVH problems with <u>engineering examples</u>

⬇

Engineering solutions

Problem definition categorized by NVH symptoms

- **Problems to be solved are categorized by answering such questions as listed here.**

1. Vibration or acoustic problem?

2. Periodic phenomenon?

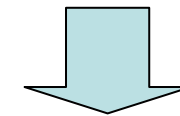3. Continuous or Intermittent?

4. Is the frequency Constant?

5. Rigid or flexible object ?

6. Transmission problem?

7. Subjectively evaluated?

➡ 7 x 2 =14 categories

⬇

NVH General Problem Definition

NVH general problem expressed in Transmission Function

$$Y(\omega) = H_{man}(\omega)\{H_{machine}(\omega)F(\omega) + G(\omega)Y_{initial}(\omega)\}$$

$$H_{machine}(\omega) = (\frac{1}{K})\frac{\varphi_i\varphi_o}{1-(\omega/\omega_r)^2 + j2\zeta(\omega/\omega_r)} = (\frac{1}{M\omega_r^2})\frac{\varphi_i\varphi_o}{1-(\omega/\omega_r)^2 + j2\zeta(\omega/\omega_r)}$$
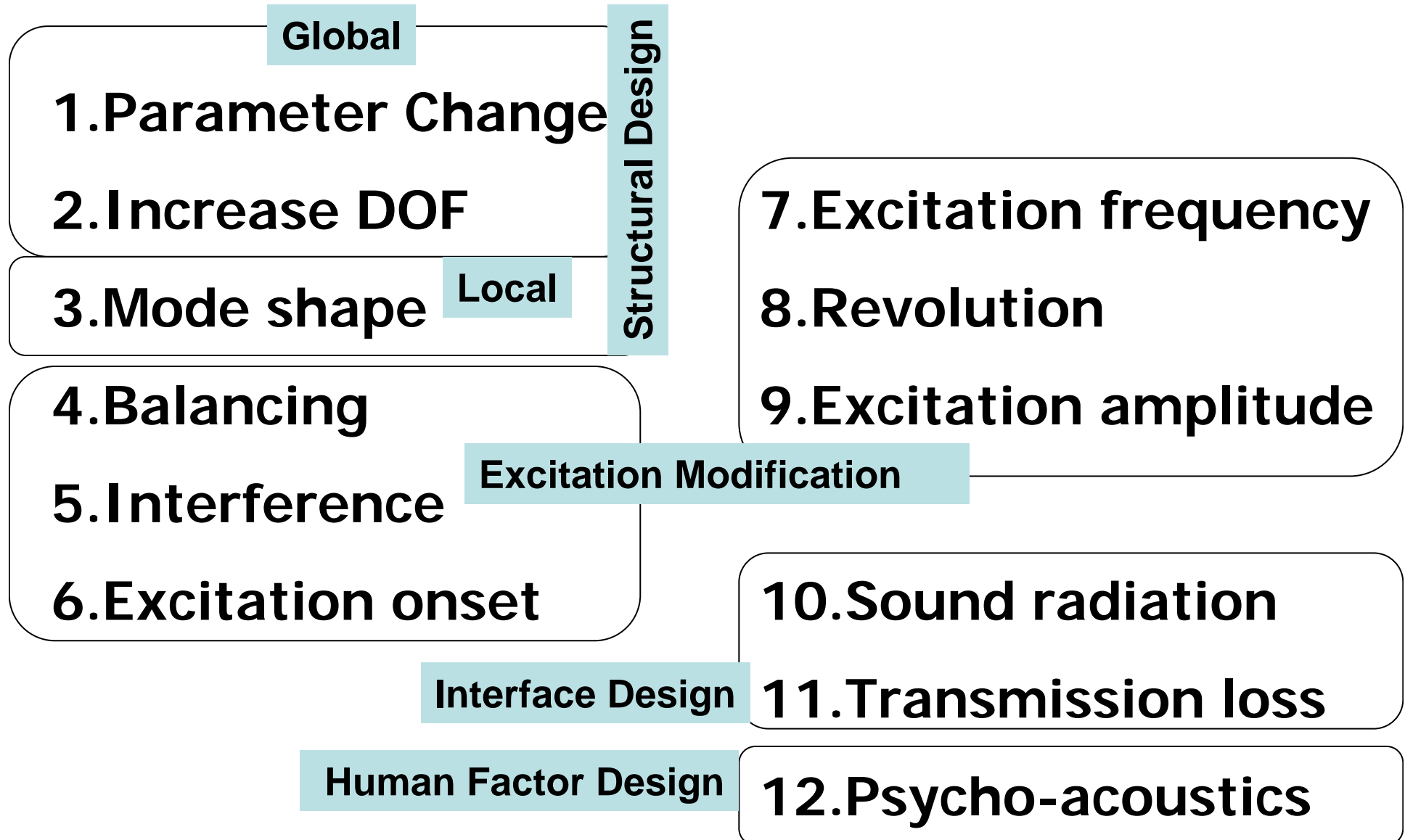
$\varphi_i\varphi_o$ **Local parameters: Mode shape functions**

$$M\omega_r^2\left\{1-(\omega/\omega_r)^2 + j2\zeta(\omega/\omega_r)\right\}$$

Global parameters
: Resonance, damping and effective mass

NVH General Solution Category

Global

Structural Design

1. Parameter Change

2. Increase DOF

Local

3. Mode shape

4. Balancing

5. Interference

Excitation Modification

6. Excitation onset

7. Excitation frequency

8. Revolution

9. Excitation amplitude

10. Sound radiation

Interface Design

11. Transmission loss

**Human Factor Design**

12. Psycho-acoustics

Examples of General Solutions

- **Category 1. Parametric change in a single degree of freedom system or in an equivalent system.**

| No.	General solutions of NVH problems	Examples of application
1-1	Adjusting fluid damping by changing orifice dimensions	Variable orifice damper used in automobile suspensions
1-2	Adjusting damping using electro-rheological fluid	Semi-active engine mounting system with an anode and a kathod placed in orifice.
1-3	Using electro-magnetic damping proportinal to velocity	Antiseismic dampers
1-4	Increase stiffness and reduce deflection by structure size reduction	Three-joint propeller shafts. / Crankshaft with a flexibly attached flywheel
1-5	Reduce stiffness for vibration insulation by a plate spring	Joints between suspension struts and a vehicle body

General Solution 1-1
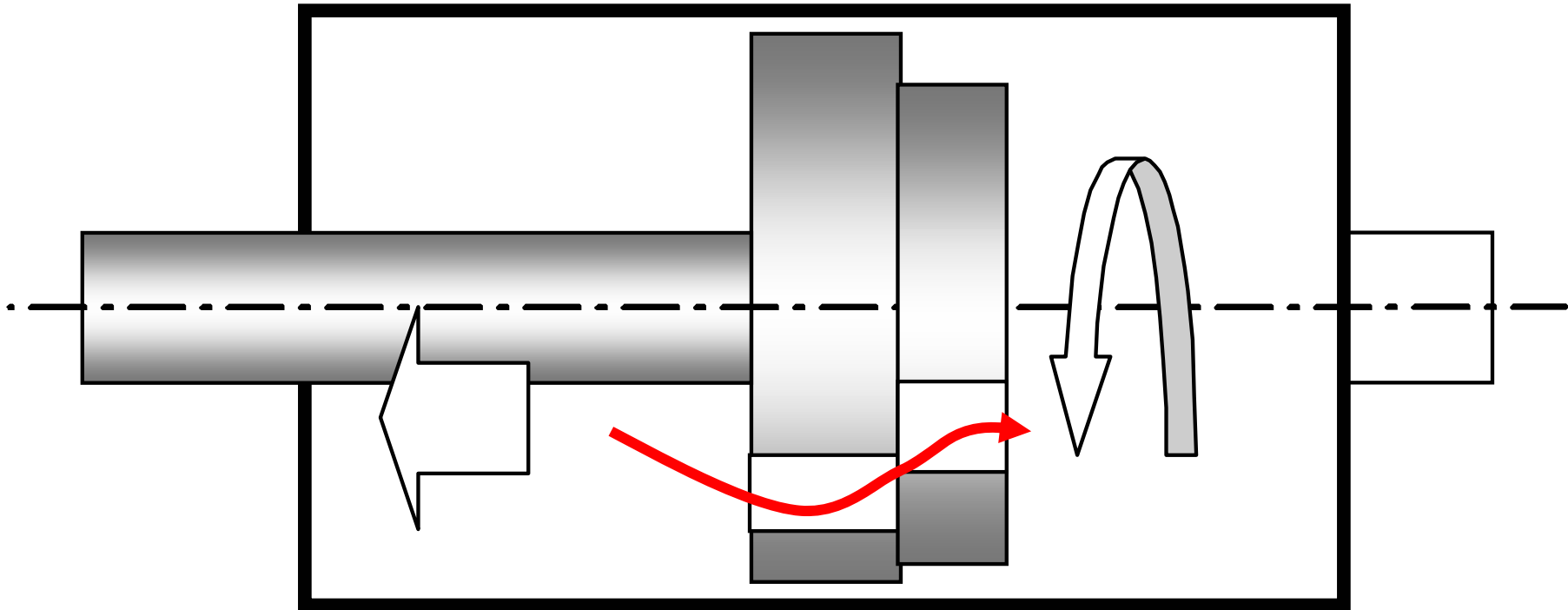
- **Adjusting fluid damping by changing orifice dimensions**
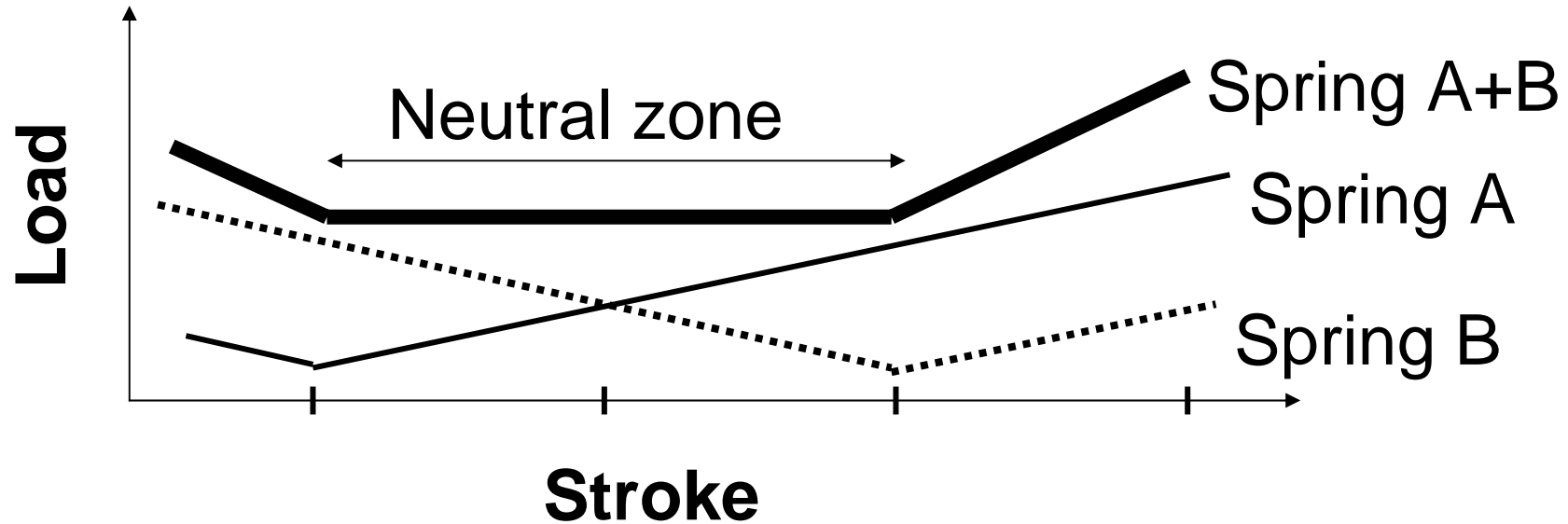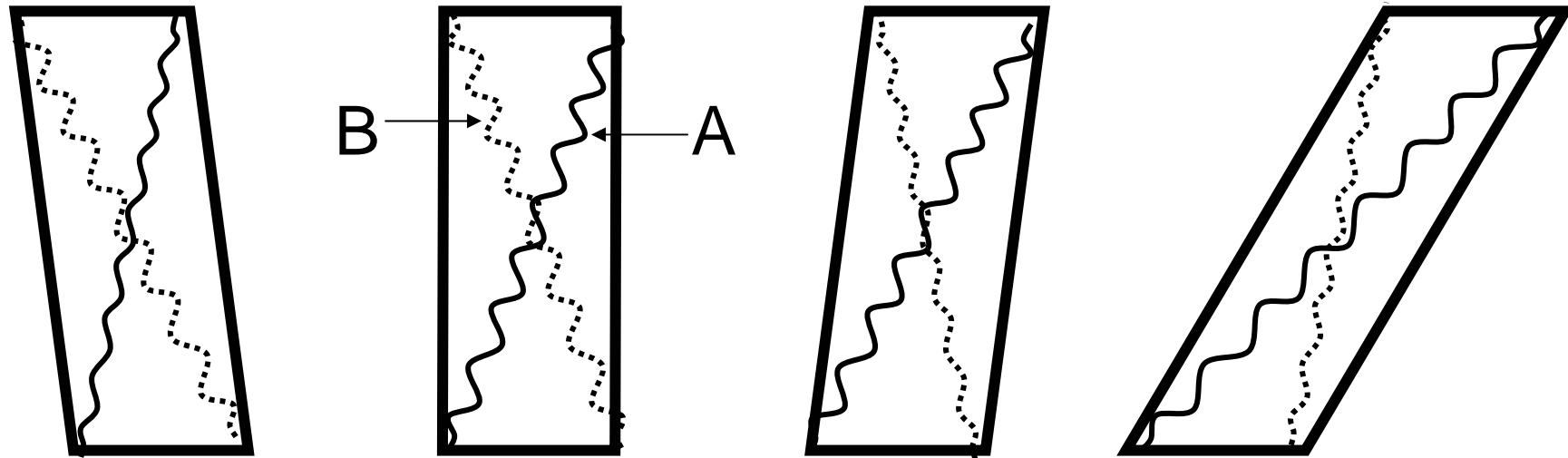
General Solution 1-2
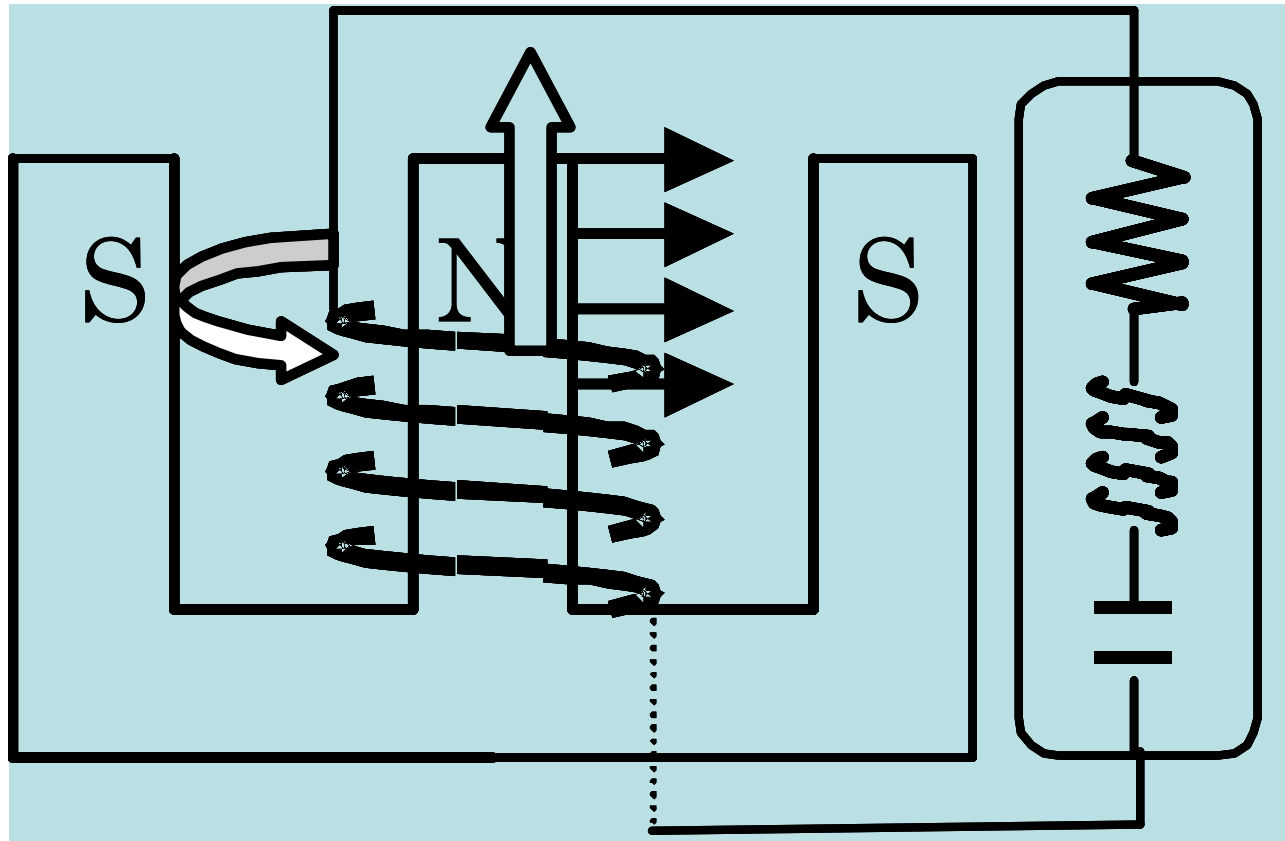
- **Using electro-magnetic damping proportional to velocity**
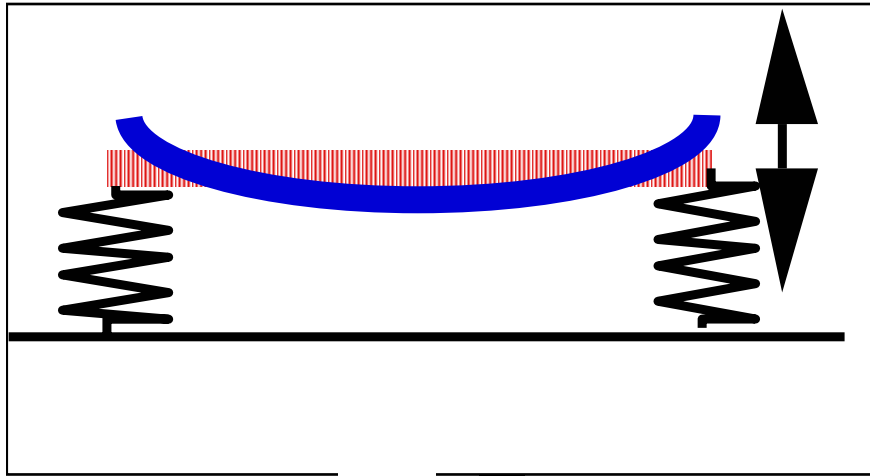
General Solution 1-5
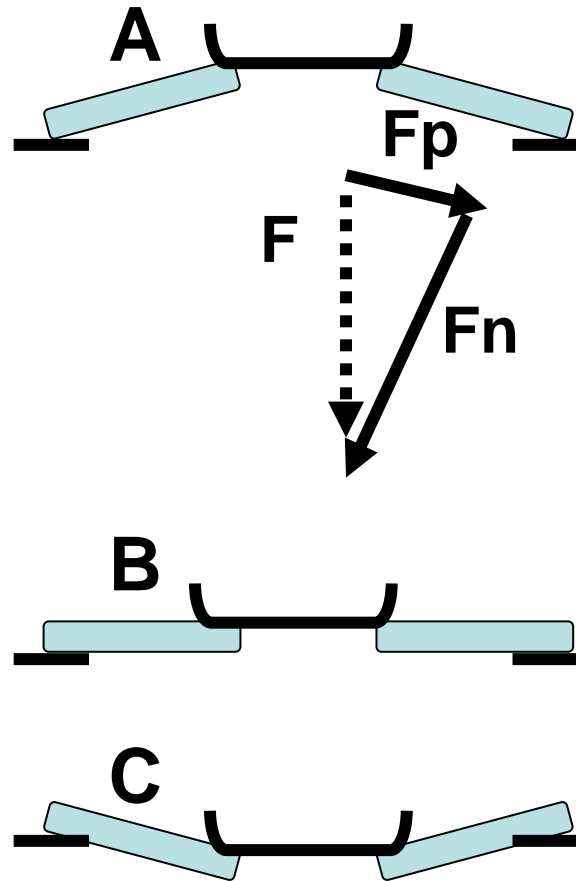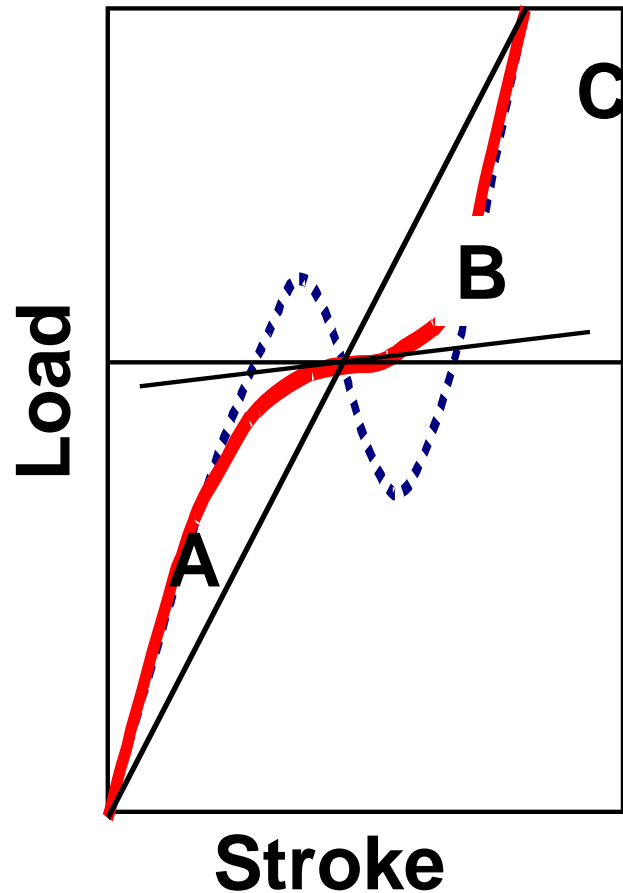
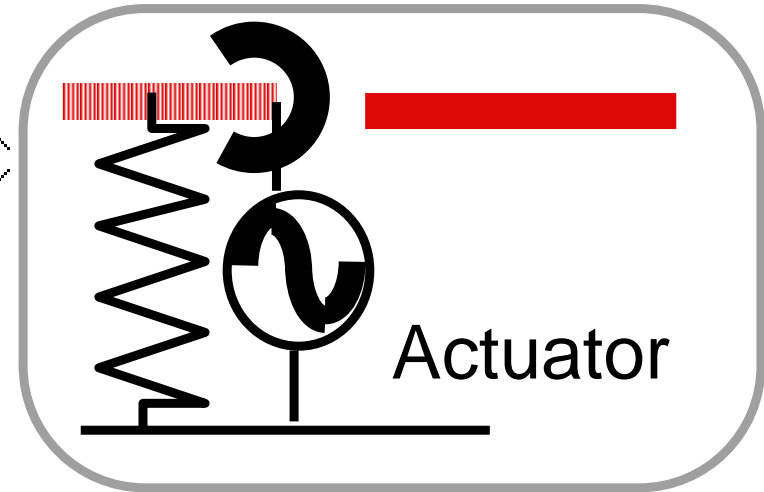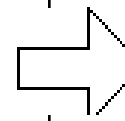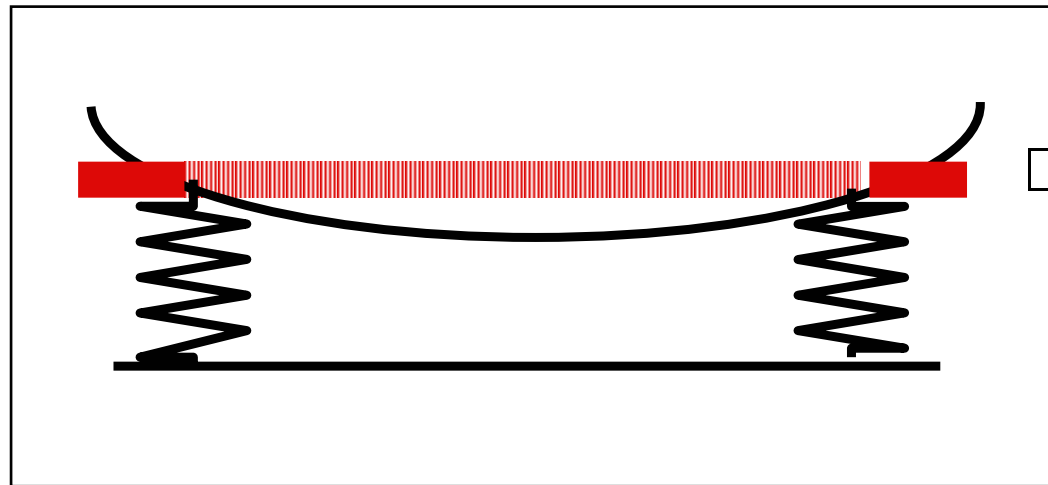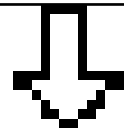- **Reduce stiffness by a dish spring while supporting static load**

General Solution 1-6

B → ← A

Neutral zone

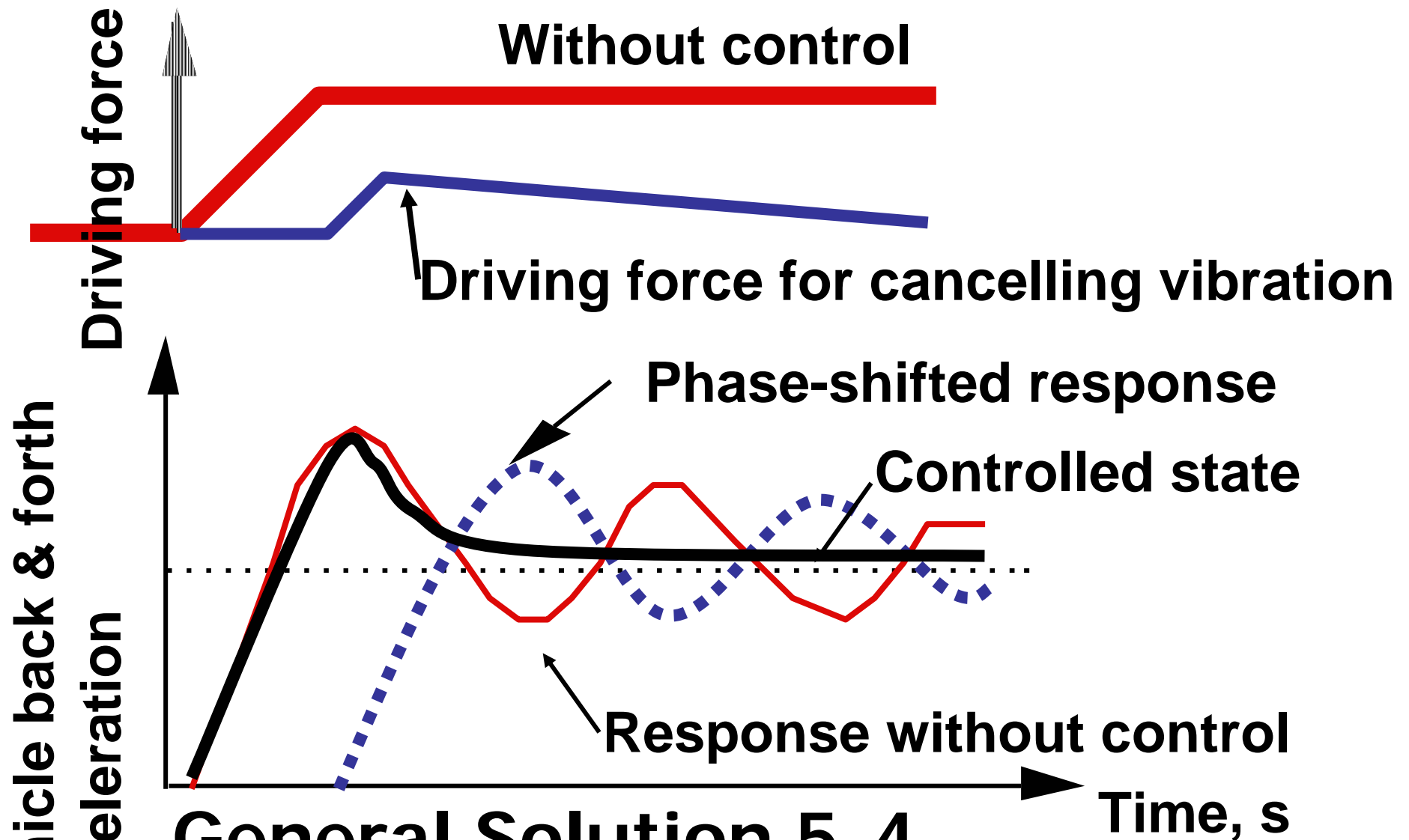**Load**

Stroke

Spring A+B

Spring A

Spring B

Reducing stiffness by pantograph mechanism

General Solution 3-1

By extending the member the overhanging gives reaction force as if there were an actuator.

Actuator

Moving vibration nodes to supporting points

Without control

Driving force

Driving force for cancelling vibration

Phase-shifted response

Controlled state

Response without control

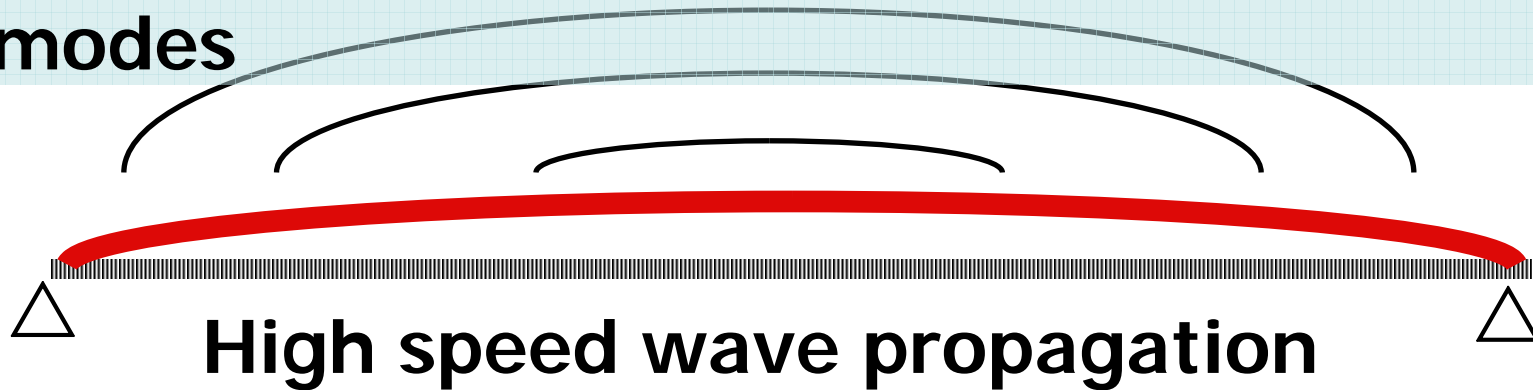**Vehicle back & forth acceleration**
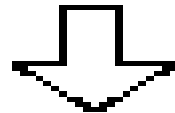
Time, s

General Solution 5-4
Adding phase-shifted responses to suppress car jerk

General Solution 10-1
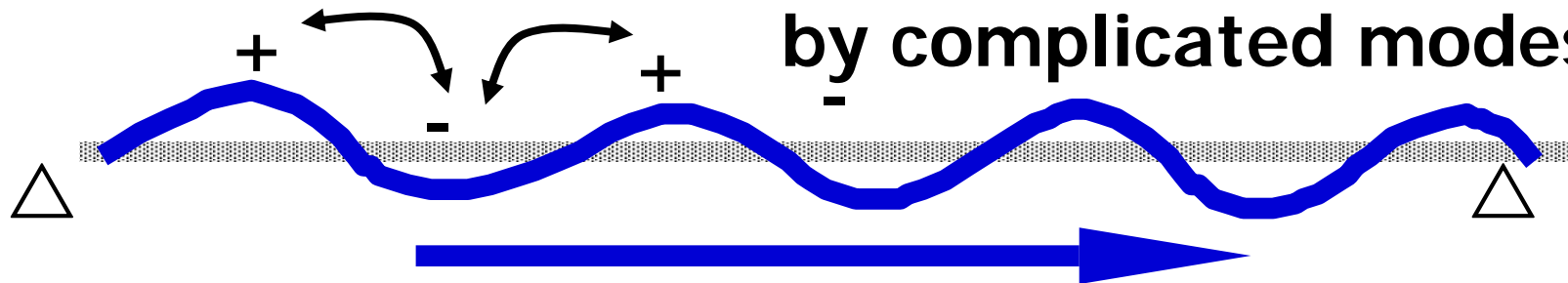
High radiation efficiency via simple vibration modes

High speed wave propagation

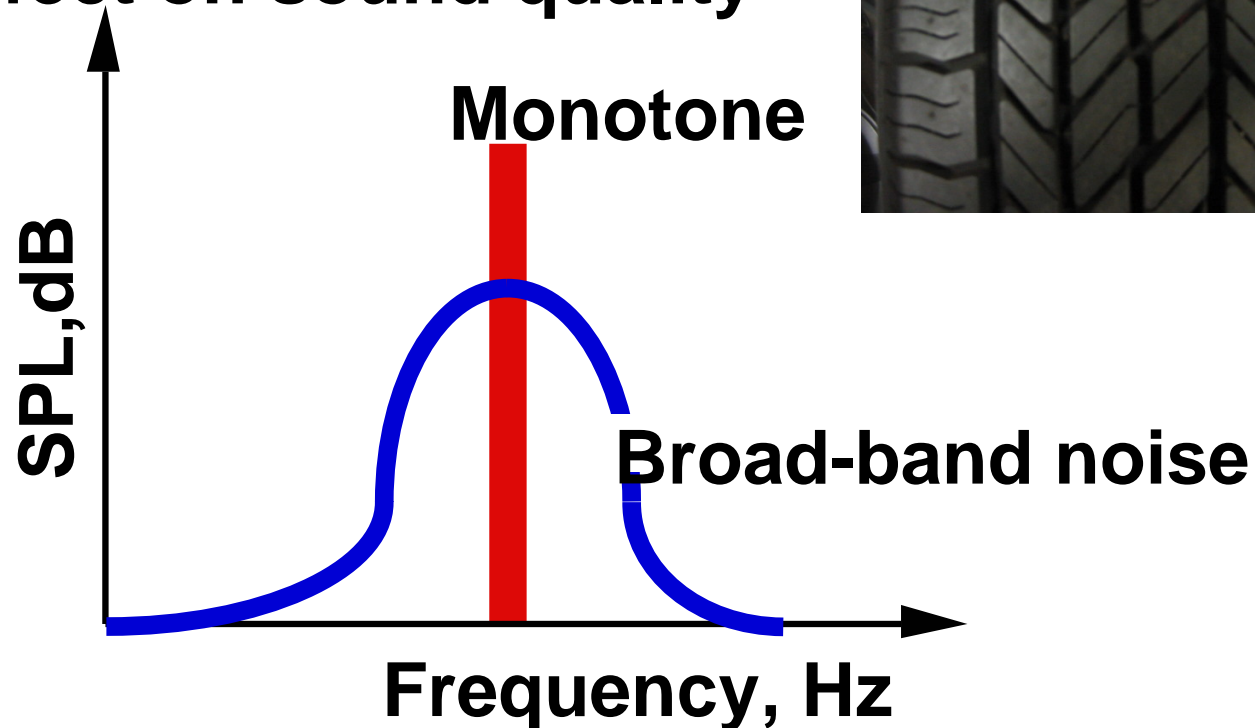Interference

Low radiation efficiency by complicated modes

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−

Wave propagating speed reduction for low radiation efficiency

General Solution 12-2

From monotone to broad-band noise

Randomized tire tread pattern

Tonality has negative effect on sound quality

Monotone

Broad-band noise

SPL,dB

Frequency, Hz

Conclusions

- Conventional vibration control approach can be used in TRIZ approach.

- Transmission function is useful in transferring from discrete problems to general problems and obtaining general solutions.