ACTIVE VIBRATION CONTROL FOR ELEVATORS

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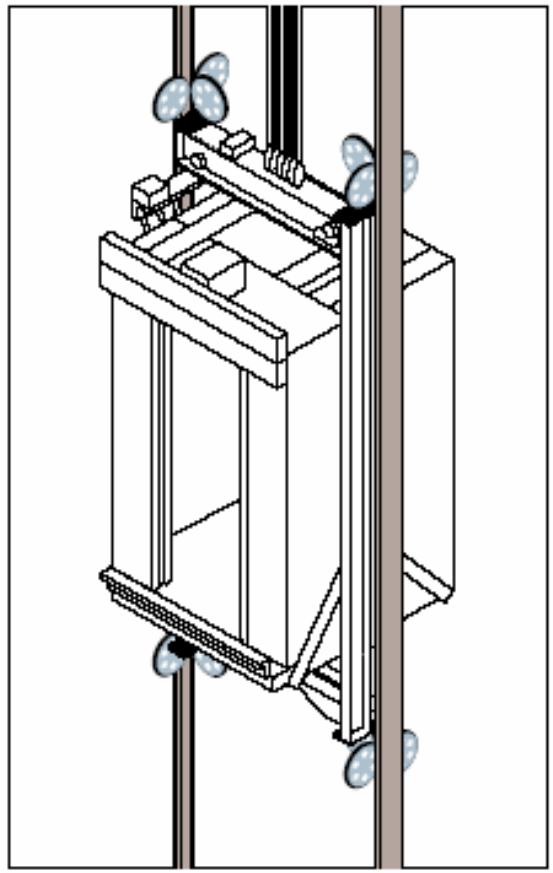
ABSTRACT

Elevator horizontal motions are usually restrained using slider or roller guides located at the top and bottom of the elevator frame. The cost of this apparatus is high because associated guide rails run the entire length of the hoistway and must be aligned horizontally to within millimeters. Also, complications arise as building distortions (due to temperature, wind, and aging) necessitate the realignment of the rails. The problems are especially acute in high-rise elevators operating above 5 m/s and rises to 400 m and beyond. These elevators invariably use roller guides having spring/damper restraint of the rollers. The springs and dampers are tuned in a manner akin to that used for automotive suspensions. Once roller guides are optimized it is found that performance is compromised by unbalance forces due to varying passenger loads and rail distortions. A way of improving these problems is the use of acceleration sensors on the elevator frame and position transducers at the roller guides. The signals from these sensors are fed into a digital control system that drives forcers attached to each of the rollers. Attainment of performance improvements economically is a great engineering challenge. The challenges relate to structural resonances, non-steady system parameters, doing laboratory work in hoistways, and field deployment. The nature of these challenges is discussed and illustrated with examples.

INTRODUCTION

- Elevator ride quality ---horizontal / vertical
- Elevator frame is constrained horizontally by imperfect T-shaped rails
- Connection from frame to rails is by spring-loaded and damped rollers for high-speed elevators
- Roller guides mitigate the effects of rail misalignment
  - Active guides using feedback controls have higher performance potential
- Economic drivers are:
  - Costs of initial and periodic rail alignments
  - Costs of guidance system and related maintenance
  - Customer satisfaction: ride quality and reliability
- Passive vs. Active determined by economics
- Application of active controls is to high-rise, high-speed elevators– typically, speeds above 5 m/s, rises to 400 m and beyond

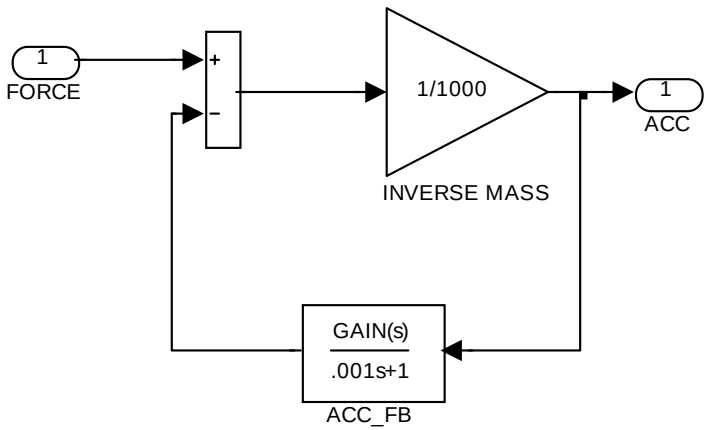


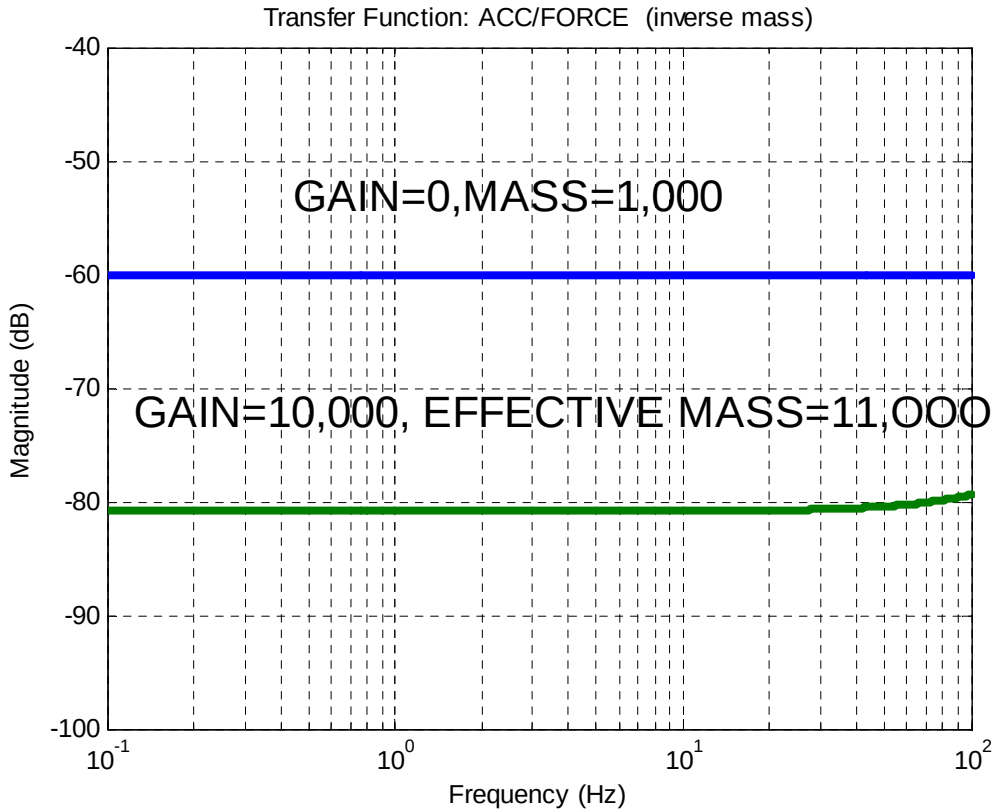
Drawing taken from Otis Elevator Company sales brochure

CHALLENGES

- Controls :
  - Bandwidth (speed of response, allowable feedback gain)
  - Stability margins
    - Structural resonances
  - Dealing with position limits (centering controls)
    - Nonlinearities
  - MIMO system
  - Quick set up of new equipment
- Work environment
- Cost and Reliability

ACCELERATION FEEDBACK AROUND MASS





ACTIVE VIBRATION CONTROL FOR MAGLEV VEHICLE

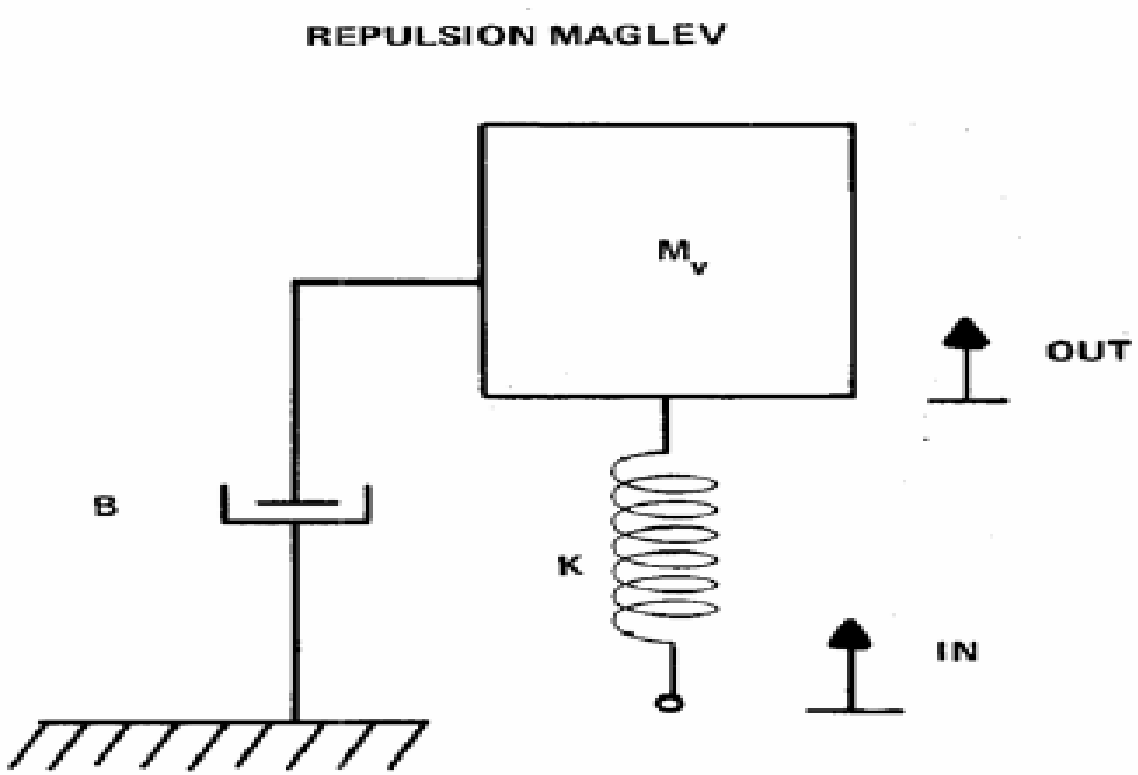


Fig. 9 Linear equivalent to vehicle system

Performance of Magnetic Suspensions for High Speed Vehicles Operating Over Flexible Guideways, ASME Transactions, JOURNAL OF DYNAMIC SYSTEMS, MEASUREMENT, AND CONTROL; Jun, 1974

Conventional Elevator

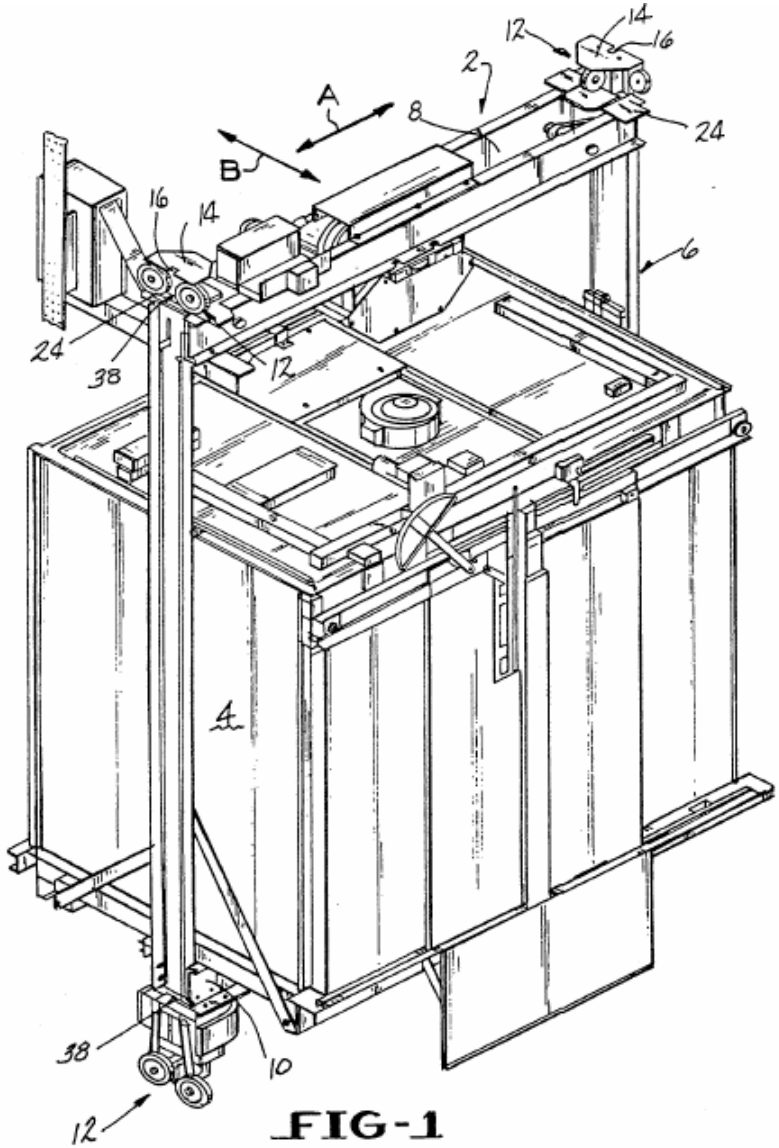


FIG-1

Taken from US Patent 5,117,946

4 CAB

FRAME:

- 10 SAFETY PLANK
- 8 CROSSHEAD
- 6 STILES

A SIDE/SIDE MOTION

B FRONT/BACK MOTION

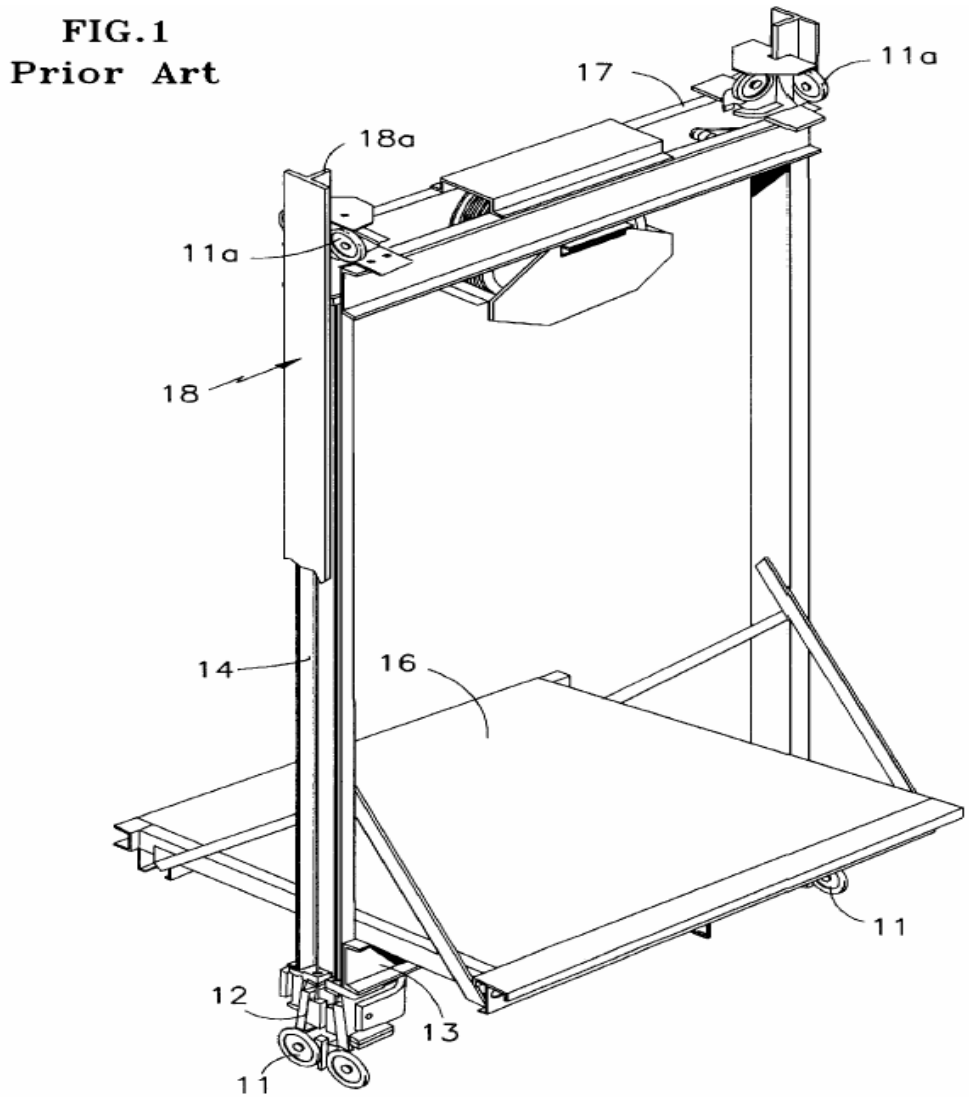
FRAME AND PLATFORM

14 Stile

18 Guide Rail

17 Crosshead

16 Platform



Taken from US Patent 5,816,369

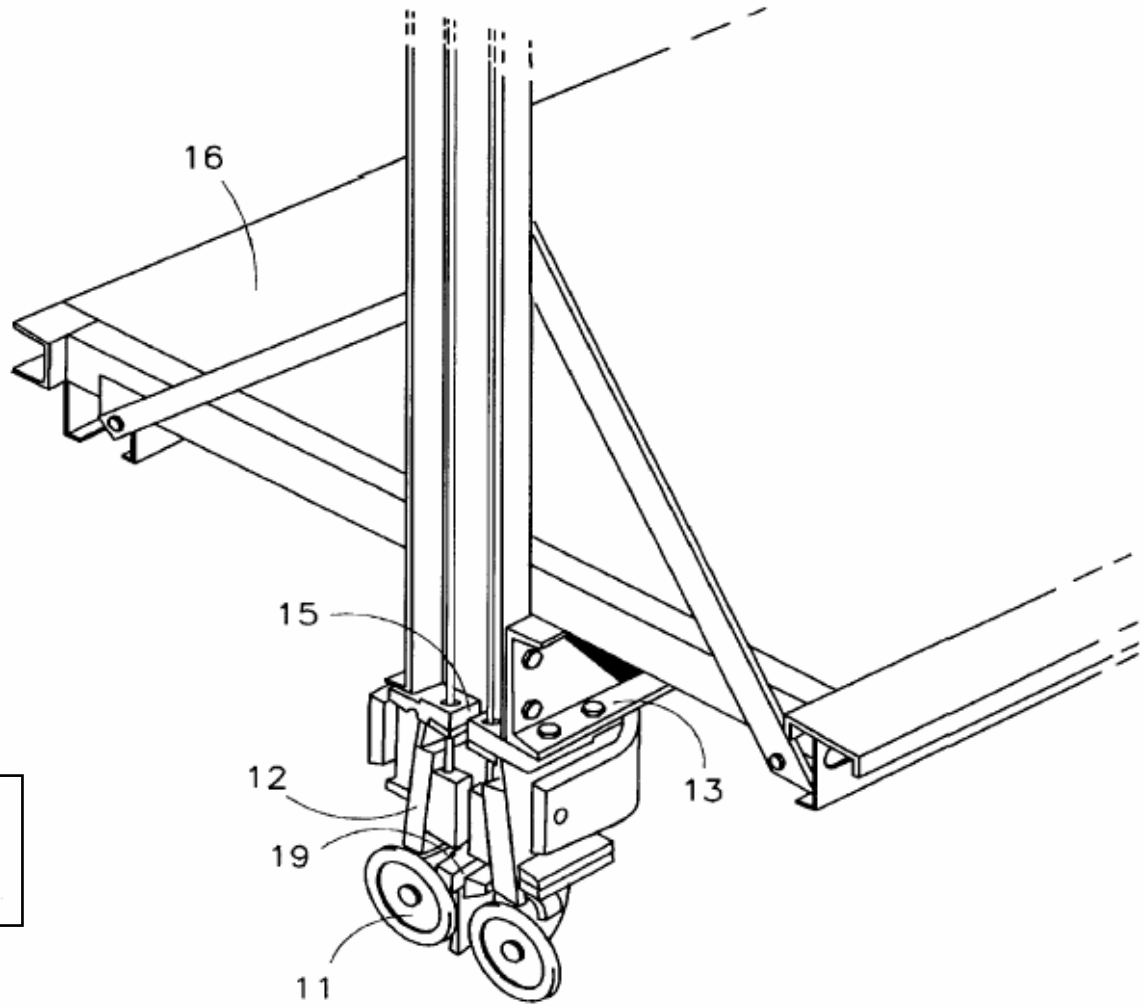
SAFETY PLANK, SAFETY, ROLLER GUIDE

13 Safety Plank

12 Safety

11 Roller Guide

19 Safety Throat



Taken from US Patent 5,816,369

CONVENTIONAL ROLLER GUIDE

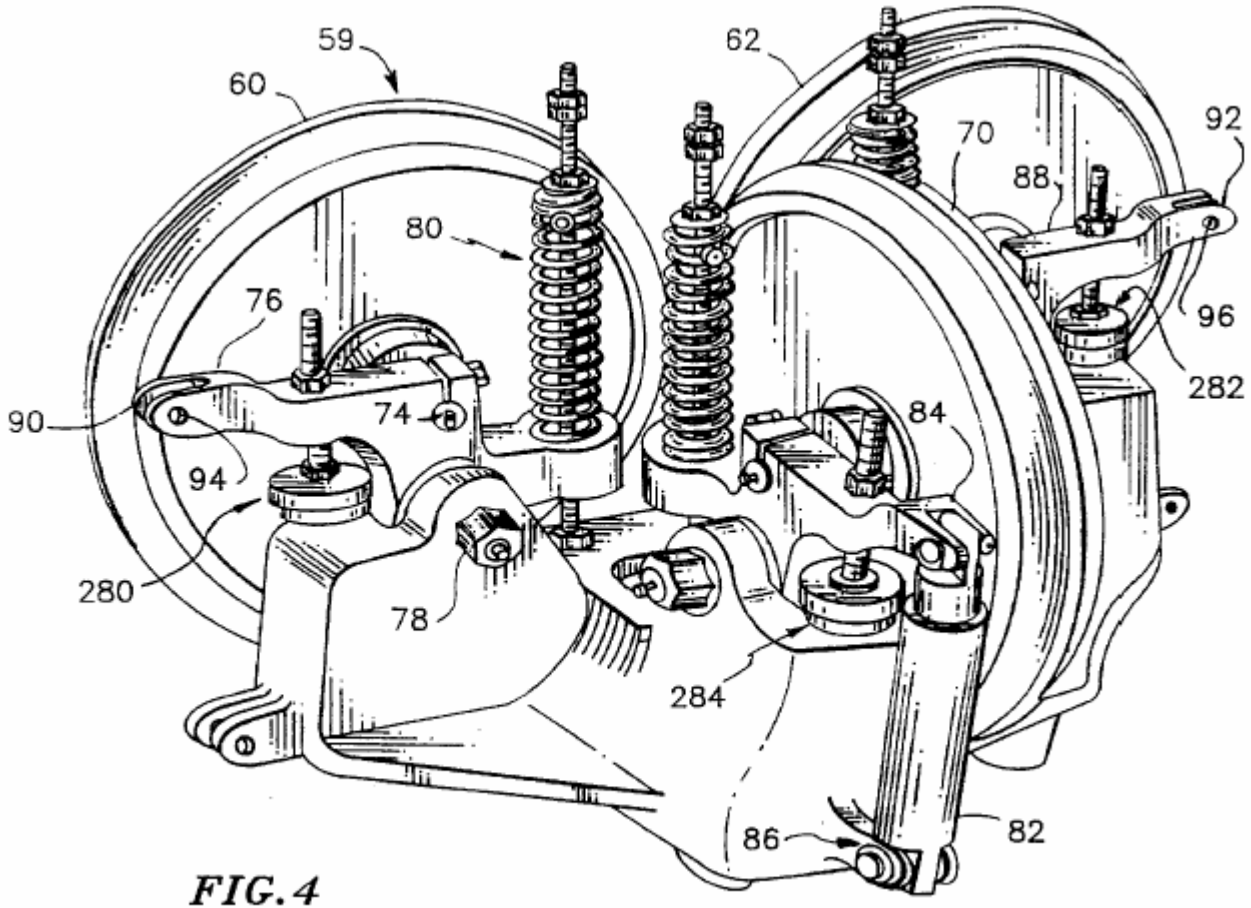
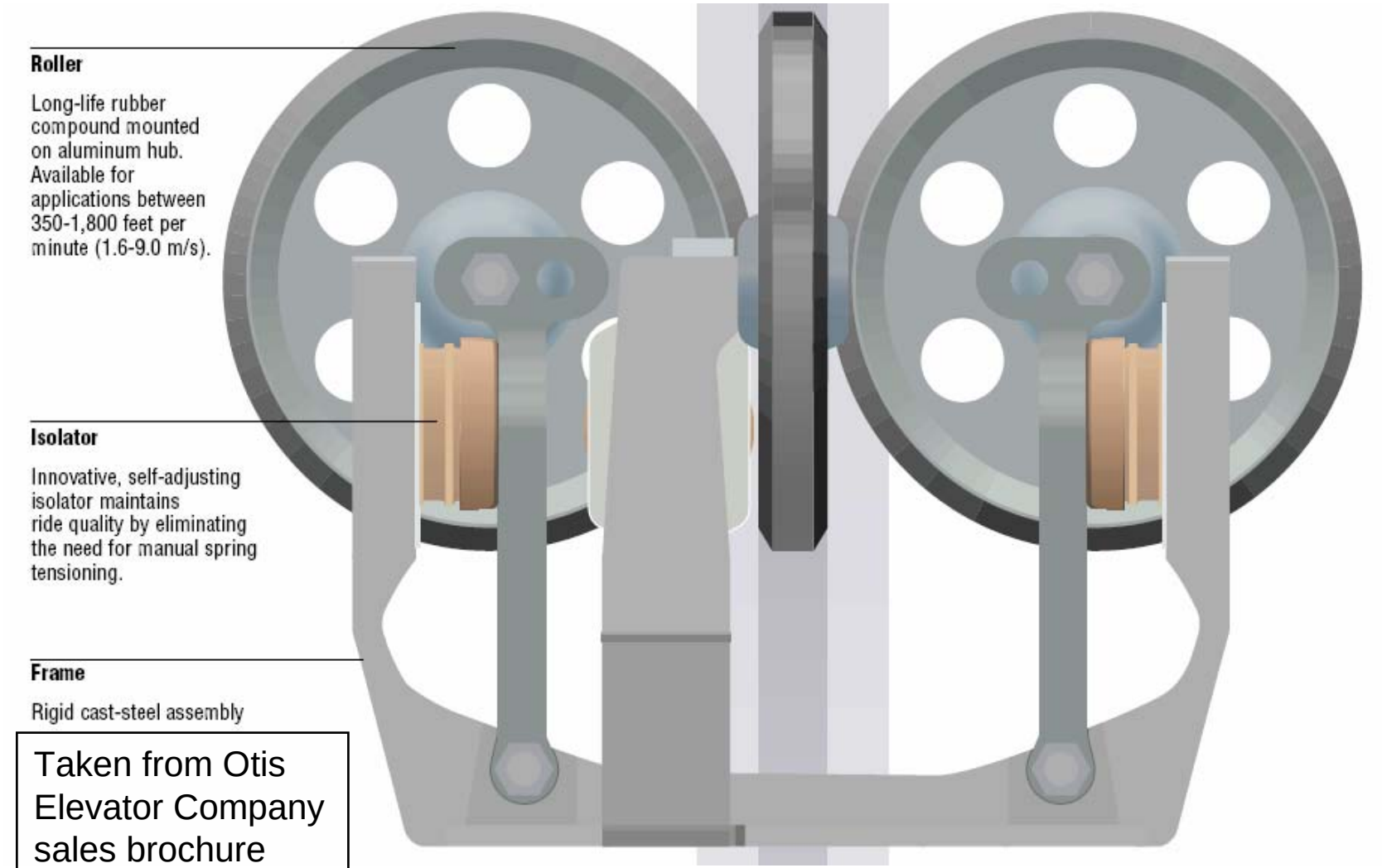


FIG. 4
(PRIOR ART)

Taken from US Patent 5,535,853

OTIS ULTRA ROLLER GUIDE

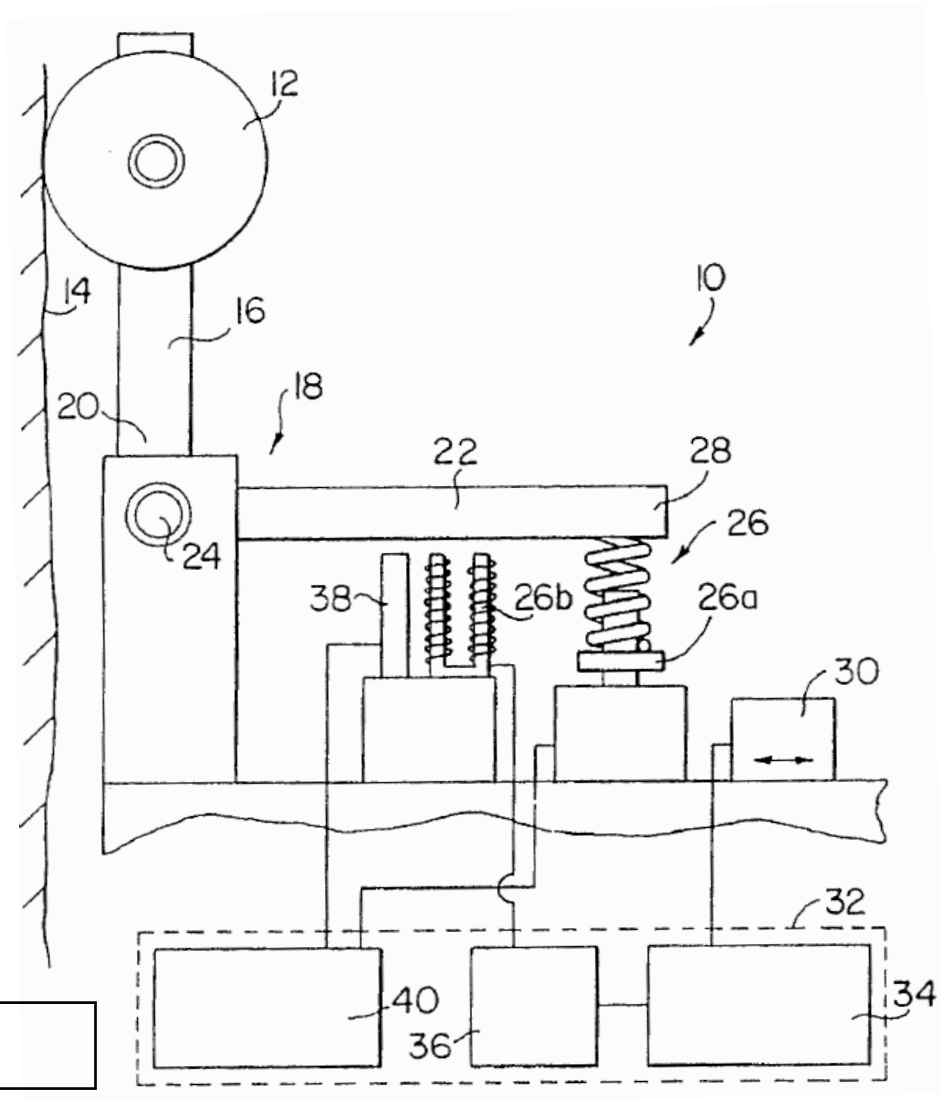
"…reduce vibrations by as much as 50% over conventional roller guides."



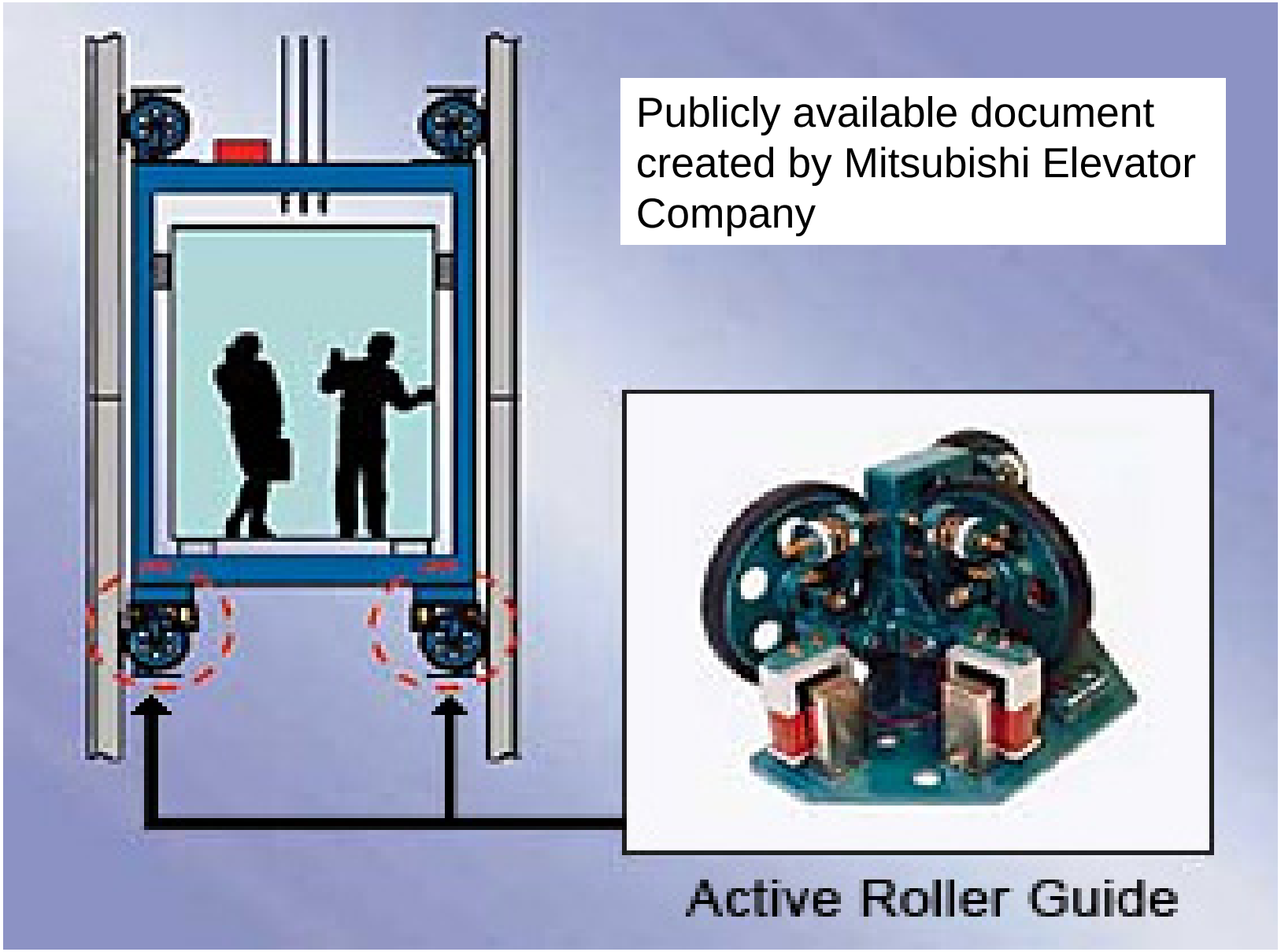
Taken from Otis Elevator Company sales brochure

ACTIVE ROLLER GUIDE COMPONENTS

12. ROLLER
16, 22. ARM
26b. ELECTROMAGNET
38. POSITION SENSOR
26. SPRING
26a. POSITION DRIVE
30. ACCELEROMETER
40. CENTERING CONTROL
36. MAGNET DRIVER
34. VIBRATION CONTROL



Taken from US Patent 5,597,988


Publicly available document created by Mitsubishi Elevator Company
Active Roller Guide

ADVANTAGES OF ACTIVE ROLLER GUIDE SYSTEM

- Suppresses Horizontal Vibrations without Rail Realignment
- Stiffens Car Against Aerodynamic Forces
- Permits Reduction of Vibrations by Factor of 3 to 10 (10 to 20 dB)
  - optimized passive systems give smaller improvements
- Economic Advantage
  - consistent high-quality ride performance
- Application to Gearless Elevators Used in High-Rise Buildings
  - modernization
  - new equipment

DEFLECTION OF ELEVATOR FRAME STILES

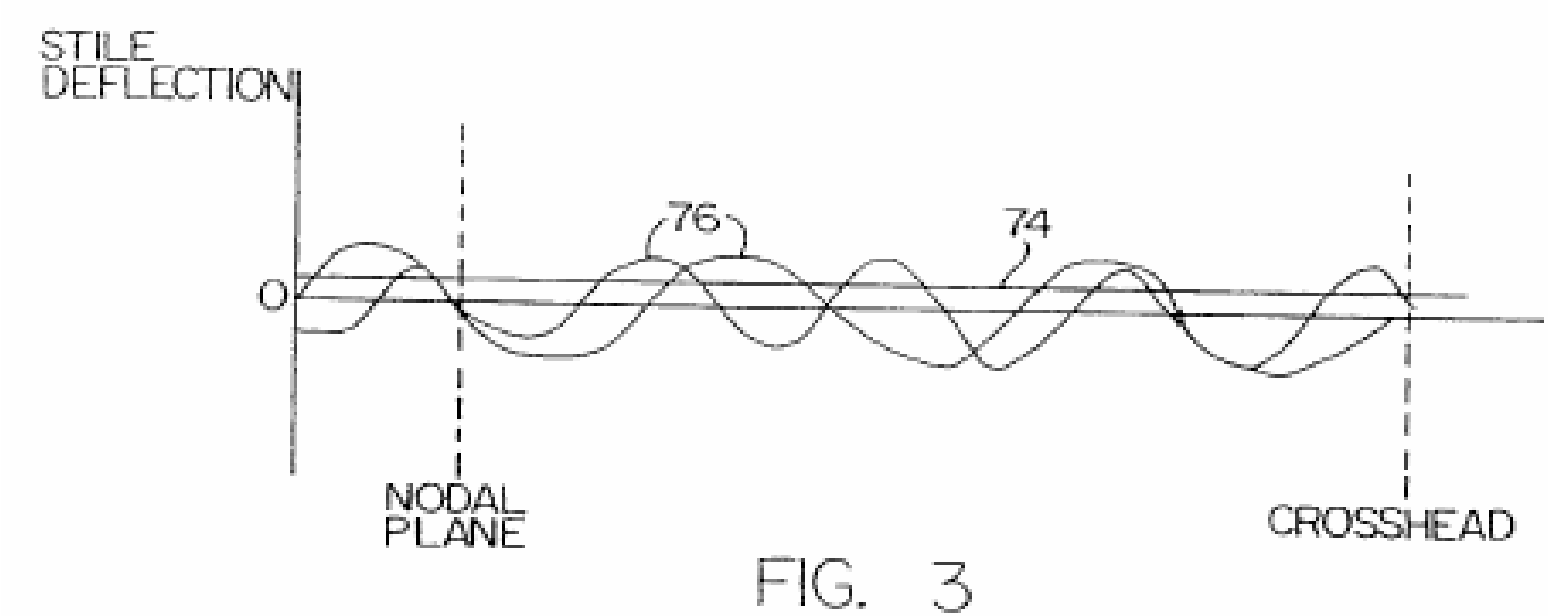


FIG. 3

Taken from US Patent 5,597,988

AMPLITUDE RESPONSES ILLUSTRATING SPATIAL FILTERING

Taken from US Patent 5,597,988

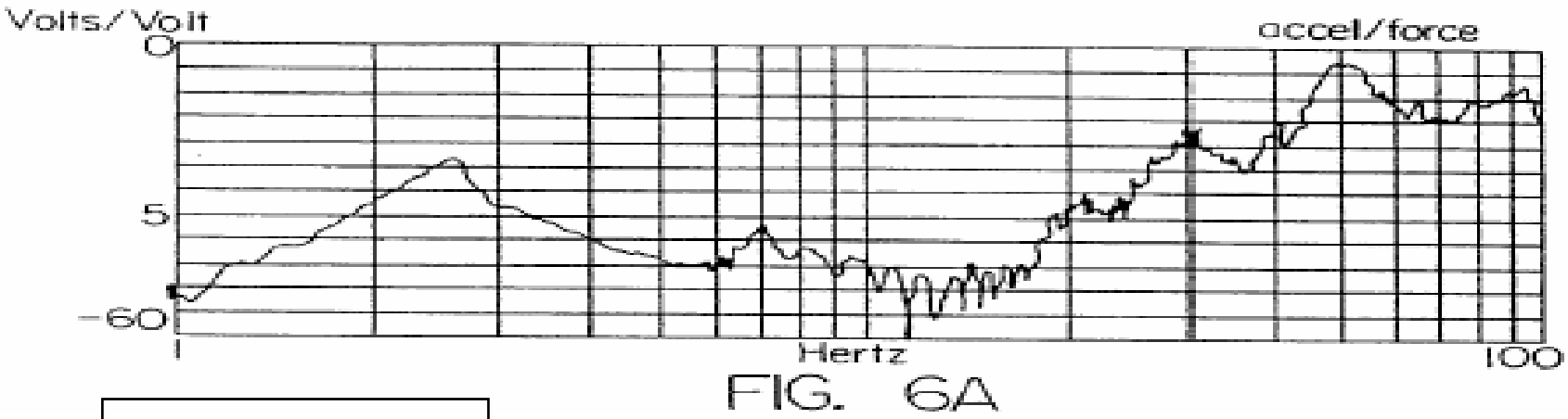


FIG. 6A

At Roller Guide

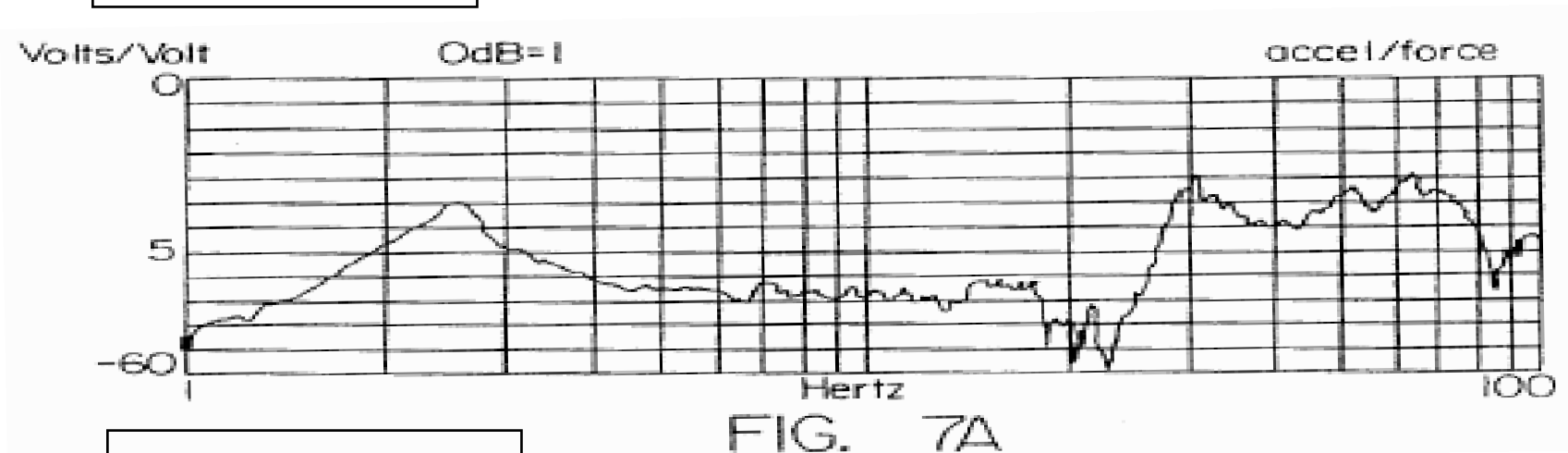


FIG. 7A

On Safety Plank

PHASE RESPONSES ILLUSTRATING SPATIAL FILTERING

Taken from US Patent 5,597,988

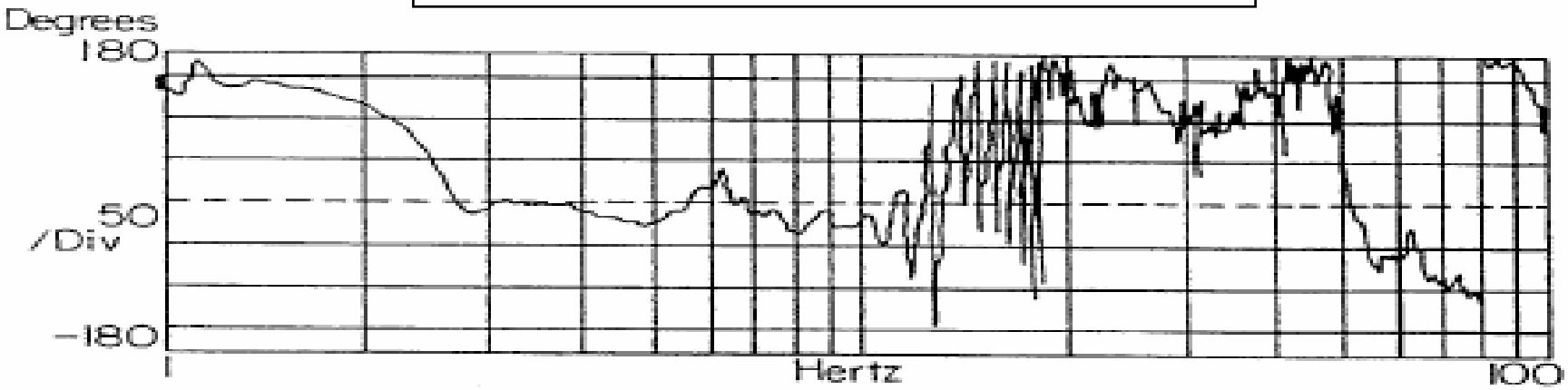


FIG. 6B

At Roller Guide

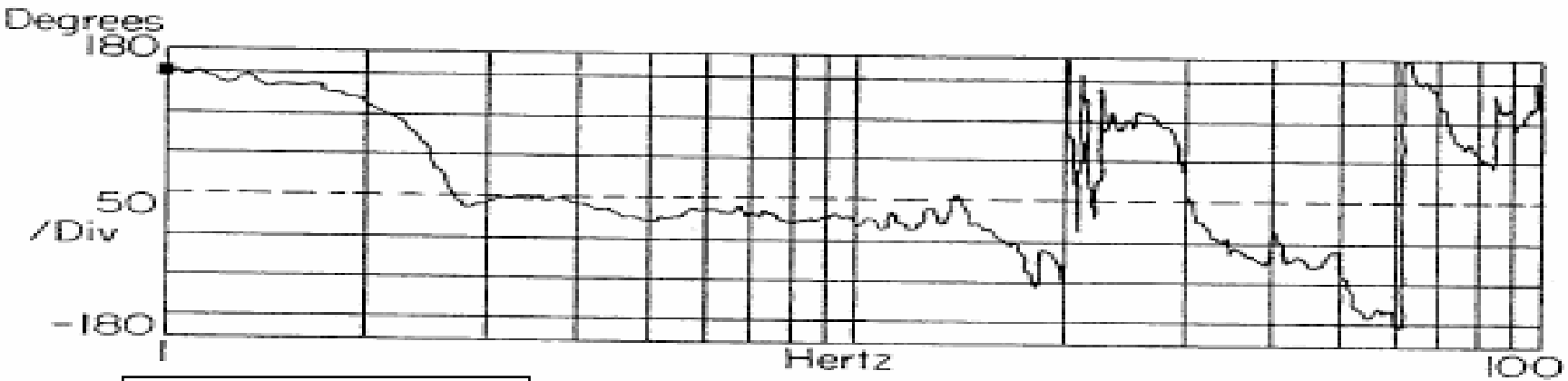
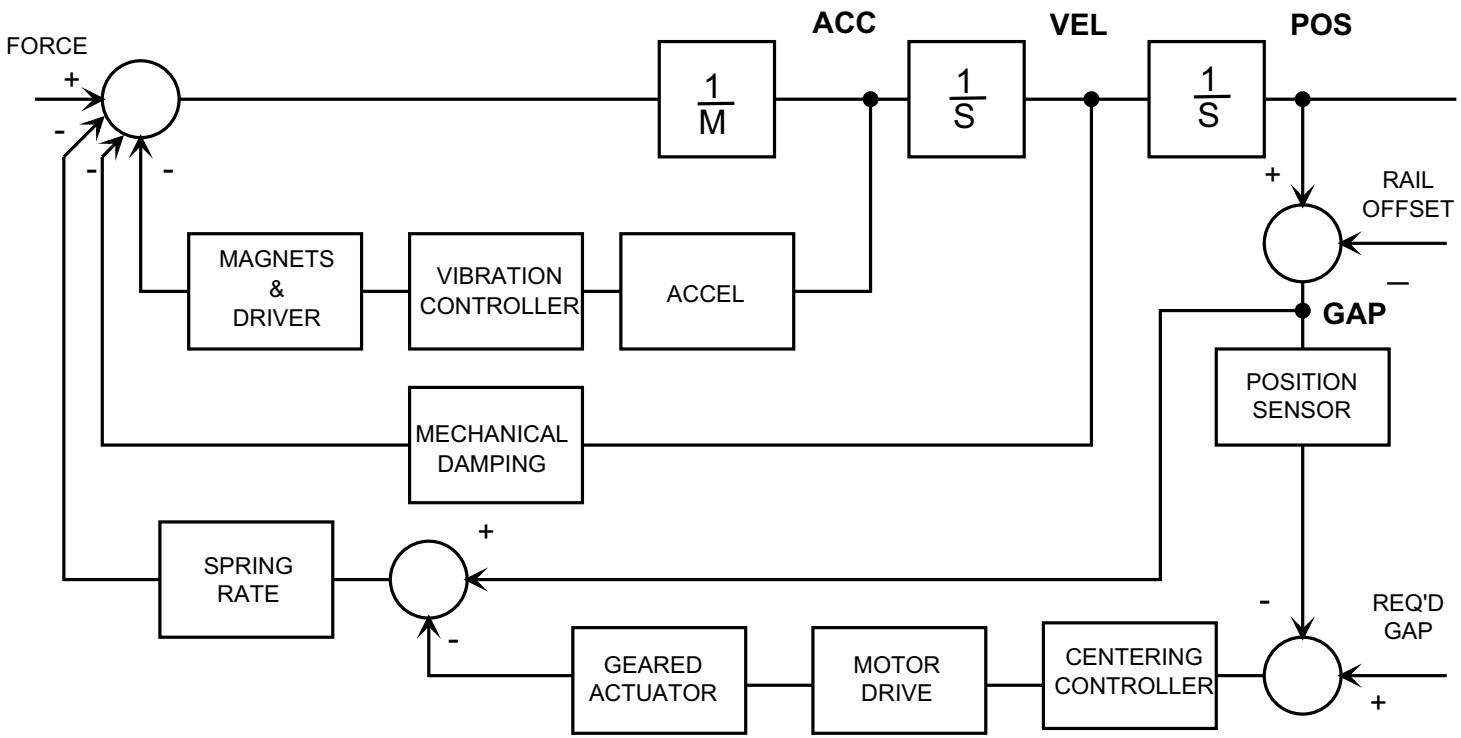


FIG. 7B

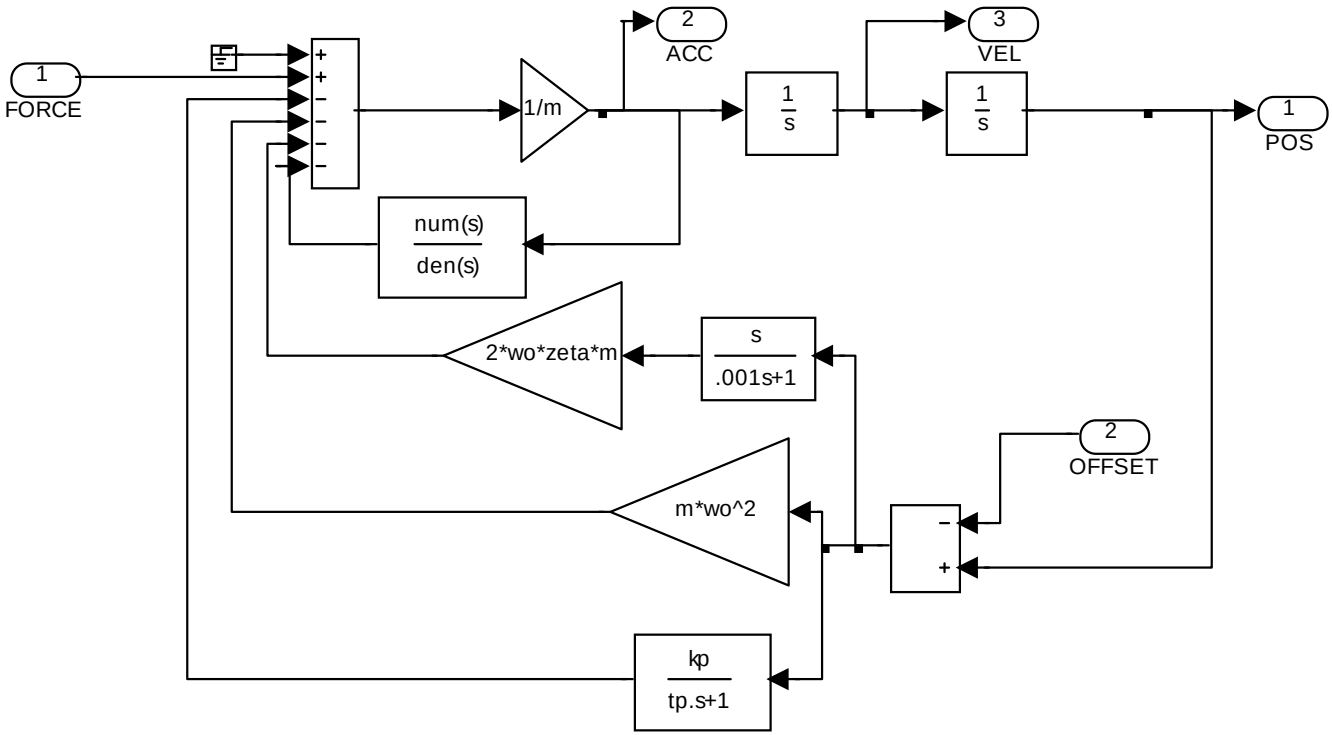
On Safety Plank

ARG CONTROL BLOCK DIAGRAM



Taken from US Patents 5,304,751, also, 5,816,369

SIMULATION BLOCK DIAGRAM



SIMULATION PARAMETERS

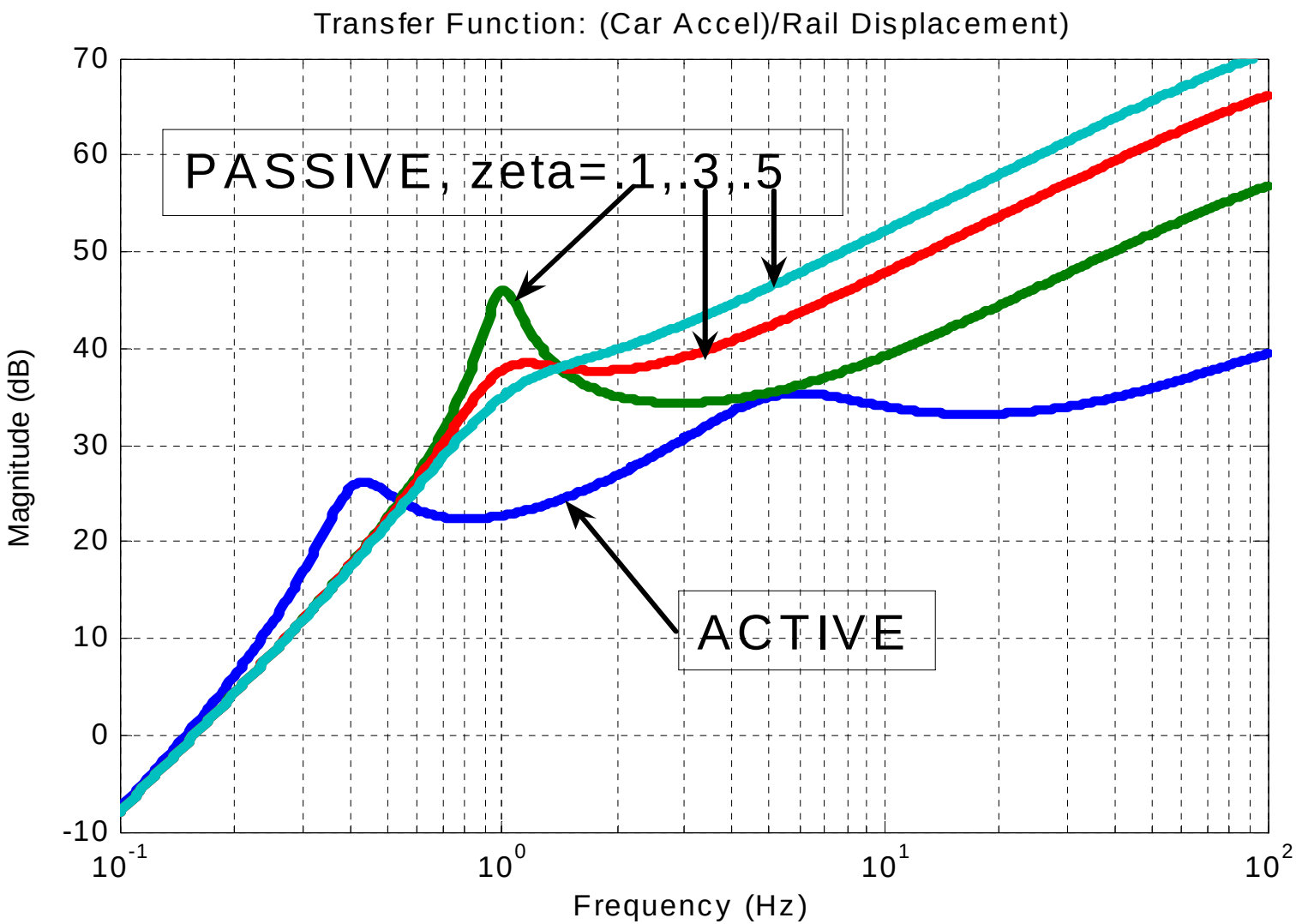
- Passive System Example
  - m = 1000 kg (effective mass)
  - g = 0
  - wo = 2*pi (natural frequency)
  - zeta = 0.1, 0.3, 0.5 (damping ratio)

- Active System Example
  - gain = 1.5, zeta=.01
  - transfer function -- units = Newton/(m/s^2)

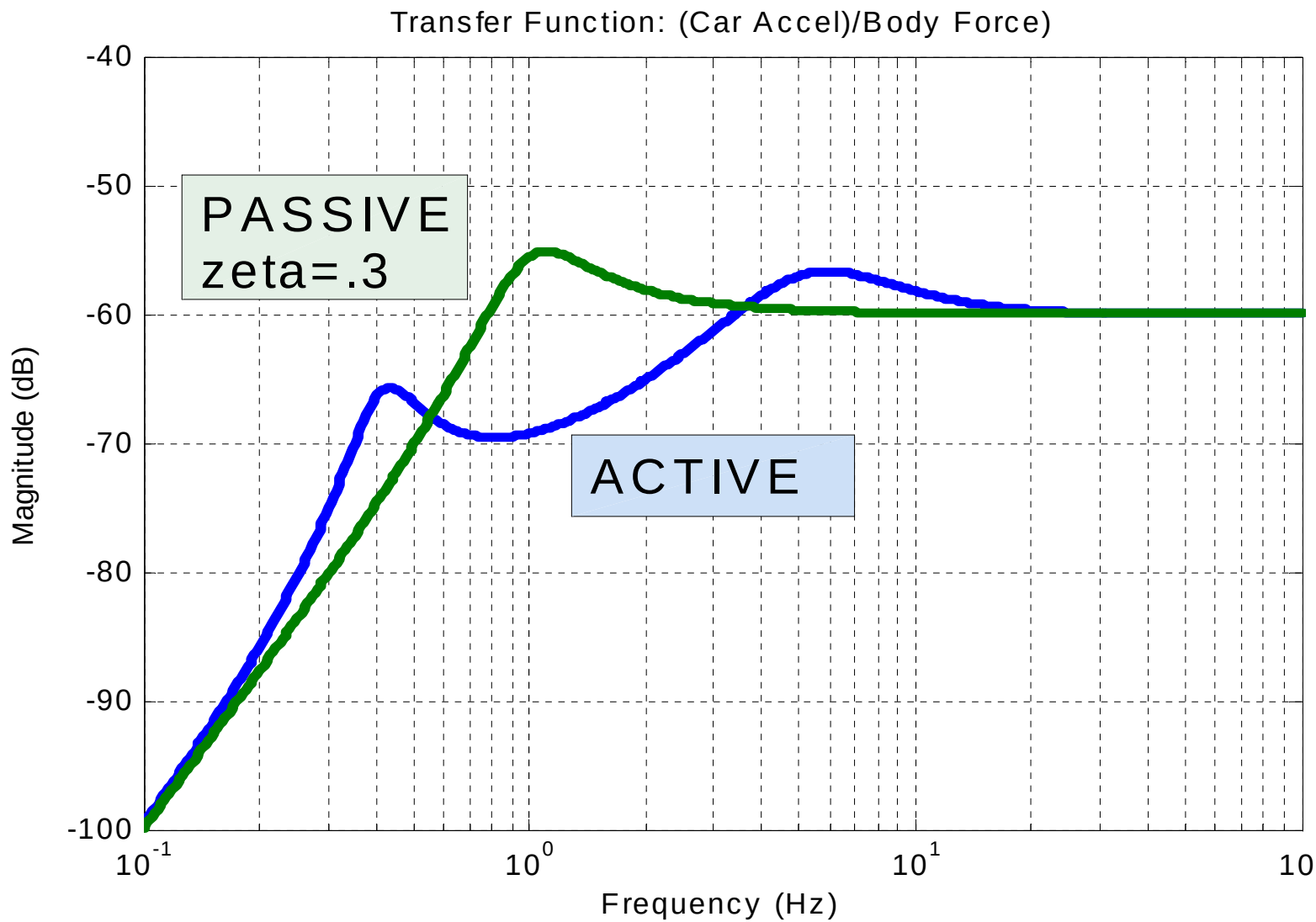
$$\frac{num}{den} = \frac{gain * 6660 * S}{(2S+1)*(.22S+1)*(.022S+1)*(.01S+1)}$$

Taken from US Patent 5,597,988, col. 5, lines 14-33

CAR ACCELERATION/RAIL DISPLACEMENT



(CAR ACCEL) / (BODY FORCE)



POSSIBLE PRODUCT CONFIGURATIONS

- 4 Passive Roller Guide Sets
- Passive Guide Sets with Centering Controls
- Passive Roller Guides on Top, Active on the Bottom
- Passive Guide Sets with Centering Controls on Top, Active on the Bottom
- Active Roller Guides Top and Bottom
- Enablers:
  - Fast, inexpensive microprocessor systems
  - Price dropping for NdFeB magnet material
  - Inexpensive accelerometers and position sensors
  - Powerful design programs such as Matlab/Simulink and mechanical design programs

GOALS

- Suggested Maximum Rail Deviations in 4 Meter Span
  - ±3 mm front/back
  - ±4 mm side/side
- Performance Goals (2 Hz Low-Pass Filter)
  - Modernizations: 15 mg ptp for one second interval
  - New Equipment: 5 mg ptp for one second interval

- Affordable
- Reliable
- Maintainable
  - Low life-cycle cost

FUTURE DEVELOPMENTS

- COST REDUCTION
- SIMPLIFIED ADAPTATION TO EXISTING ELEVATORS
- IMPROVED VIBRATION SUPPRESSION
- MORE RESPONSIVE CENTERING CONTROLS
- NEW ELEVATOR DESIGN EXPRESSLY FOR ACTIVE VIBRATION CONTROL
  - STIFFENED FRAME
  - UNIBODY CONSTRUCTION
  - LARGER RAIL TO SAFETY CLEARANCES
- SELF-ADJUSTING PASSIVE ROLLER GUIDE SYSTEMS
  - OTIS ULTRA™ ROLLER GUIDE CLAIMS THIS
- ROLLER GUIDES USING LOW-COST ADAPTIVE DAMPERS
  - PASSIVE = OTIS ULTRA™
  - ACTIVE = ?