Turbomachinery and Heat Transfer Laboratory

TECHNION Israel Institute of Technology

Development of Educational Facilities for Jet Engine Rotordynamics and Balancing

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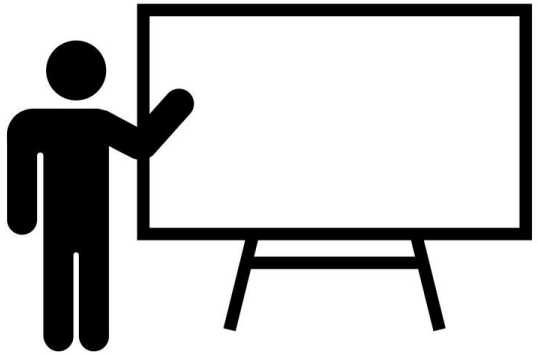
18th Israeli Symposium on Jet Engines and Gas Turbines

Turbomachinery & Heat Transfer Laboratory, Faculty of Aerospace Engineering

Technion – Israel Institute of Technology, Haifa, Israel

Presentation Layout

- Zirmey Silon project
- Jet propulsion
- Introduction
- Lab goals
- Background
- Experimental test bench
- Expectation from participating students



Zirmey Silion

- Zirmey Silon educational project aims to attract and retain talented students, as well as to enhance educational experience in the field of jet propulsion
- Launched in 2018, includes updating and creating new courses, both theoretical and experimental
- Involvement of guest lecturers from Israeli industry and IAF
- Zirmey Silon vision:
  - Enhance educational initiatives in cooperation with industry leaders and IAF
  - Develop key skills and providing cutting edge knowledge
  - Create next generation of highly qualified jet propulsion engineers
- Presented facilities are part of renewed "Propulsion & Combustion Laboratory" curriculum

Jet Propulsion

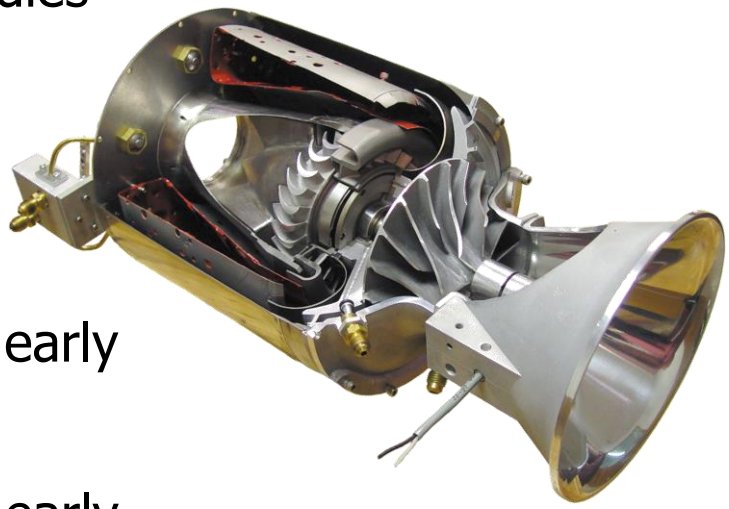
- RPM of common civil gas turbine engines:
  - CFM 56: ~ 15,000 RPM max
  - GE 90: ~ 9,000 RPM max
  - Trent 800: ~ 11,000 RPM max

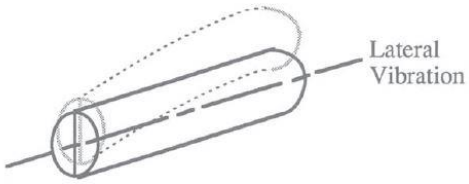
- RPM of common military gas turbine engines:
  - P&W F119: ~ 22,000 RPM max
  - GE F110: ~ 15,000 RPM max
  - Klimov RD-33: ~ 16,000 RPM max

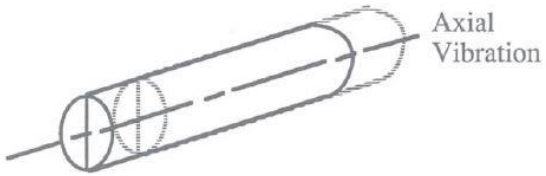
- RPM of micro gas turbines
  - AMT Pegasus: ~ 118,000 RPM max
  - AMT Olympus: ~ 112,000 RPM max
  - AMT Nike: ~ 62,000 RPM max

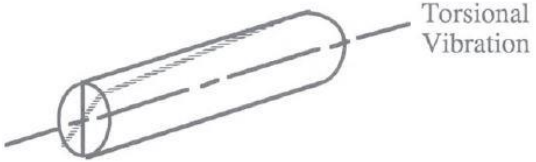
Introduction

- Rotordynamics is branch of applied mechanics
- Studies behavior of axisymmetric rotating bodies
- Critical components in gas turbine relating to
  - Safety
  - Performance
- Rotor geometry is usually determined at early design stage
- Accurate diagnosis of dynamic properties at early design stages is crucial



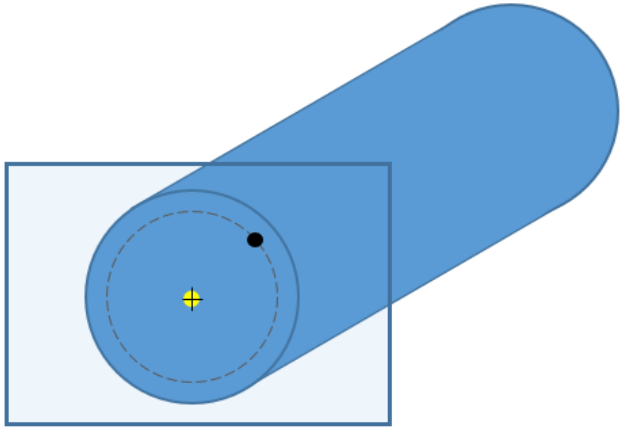


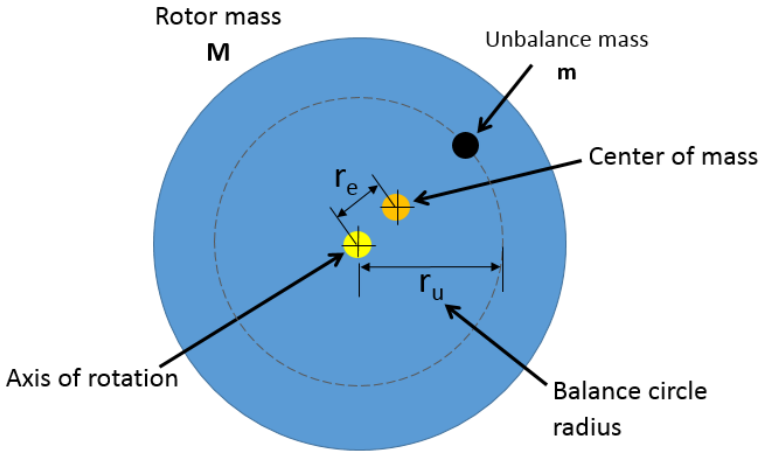




Introduction

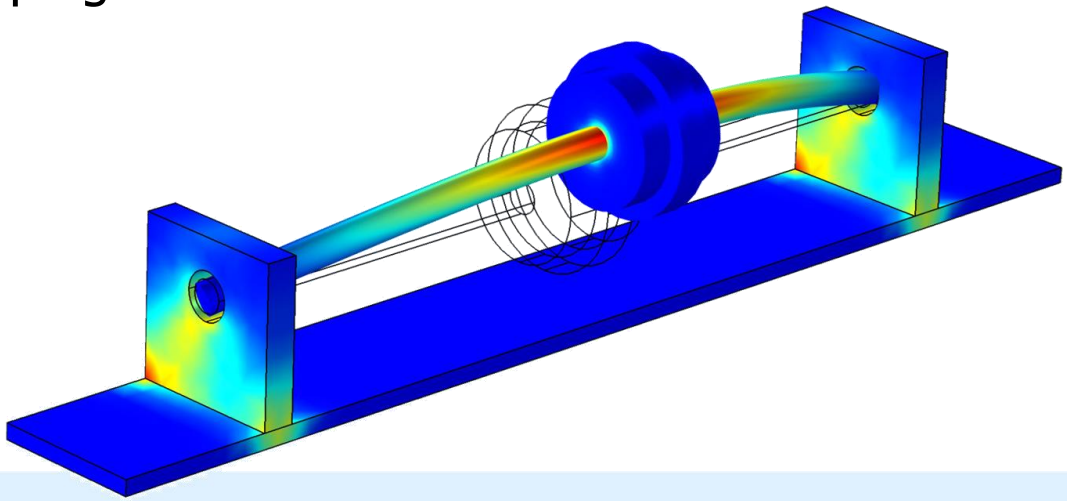
- Rotordynamics also deals with imbalanced systems
- Imbalance caused by deviation of center of mass from geometrical center of rotation
- Main causes to imbalance are:
  - Defects in manufacturing process
  - Thermal deformations
  - Accumulation of material on body
- Usually resolved by balancing – reduction of distance between center of mass and axis of rotation





Rotating System Failure

- As system's rotation speed increases, it crosses various critical modes
- In these modes, rotation speed equals to natural frequency (state known as critical speed)
  - At critical speeds, amplitude of vibrations increases
- Structural failure occurs if system stays too long at critical speed without sufficient damping

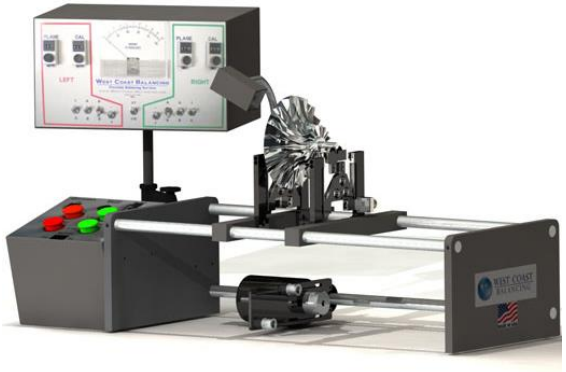


Lab Goals

- Students are exposed to these concepts of rotordynamics and balancing using two newly established test setups
- Basic rotordynamics test-bench
  - Demonstrates critical speeds and mode shapes
  - Allows vibration measurements and comparison to theory
  - Students acquire knowledge of relevant measurement techniques, data processing and Campbell diagram
- Balancing machine
  - Allows balancing by addition and reduction of mass
  - Students perform balancing procedure on SR-30 rotor

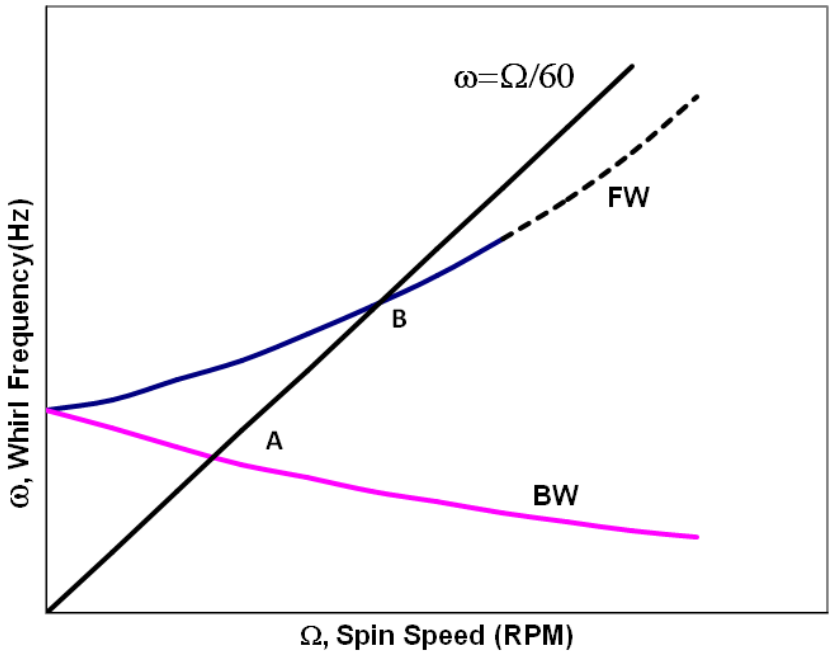
Rotordynamics Test-Bench

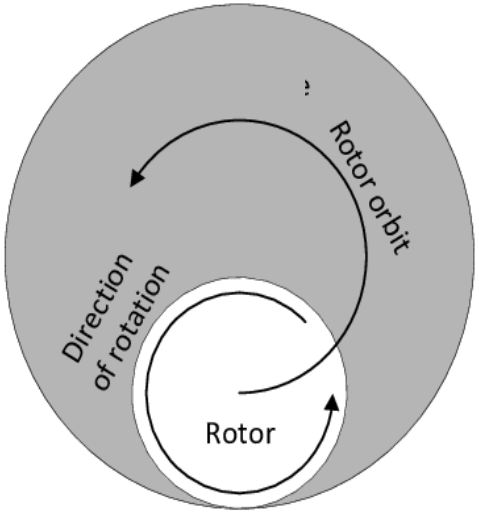
Balancing Machine



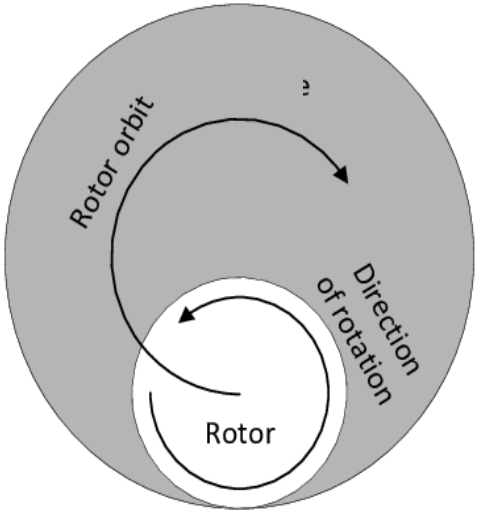
Rotordynamics Background

- Commonly, system response to rotation speed is represented graphically by Campbell diagram
- Enables to predict critical rotation speeds
  - Safe operation zones





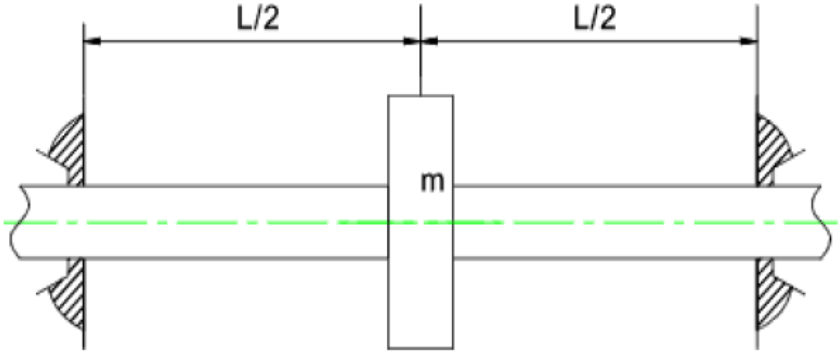
Forward whirling

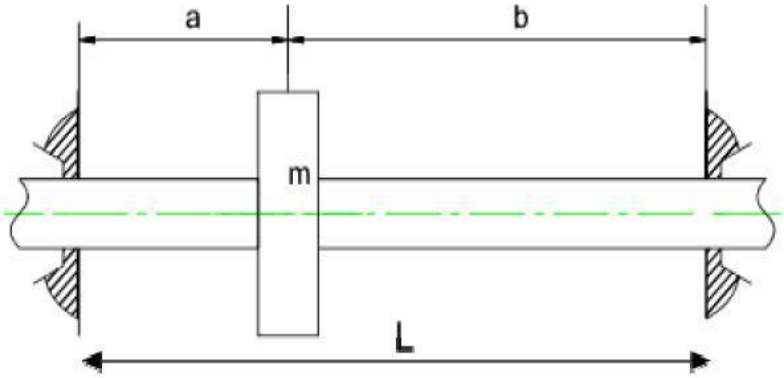


Backward whirling

Rotordynamics Background

- Known analytical solutions for "classic cases" allow to calculate critical speeds and displacements



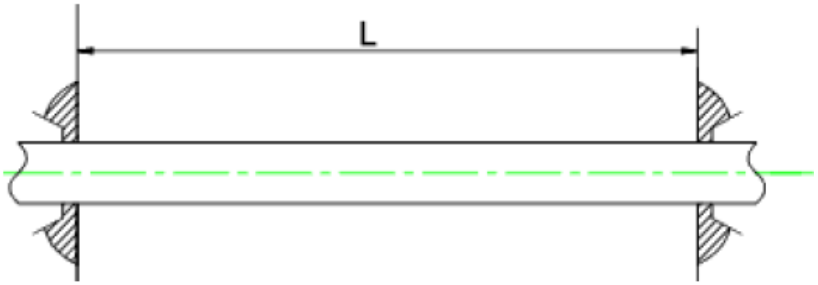


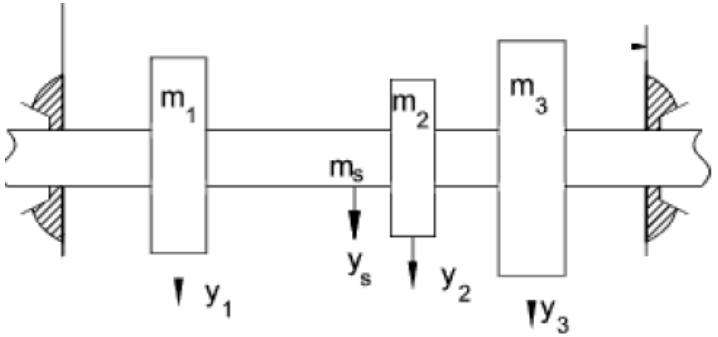
$$N_{cr} = \frac{1}{2\pi} \cdot \sqrt{\frac{48EI}{mL^3}}$$

$$N_{cr} = \frac{1}{2\pi} \cdot \sqrt{\frac{3EIL}{ma^2b^2}}$$

Rotordynamics Background

- Known analytical solutions for "classic cases" allow to calculate critical speeds and displacements





$$N_{cr} \approx 9.87 \cdot \sqrt{\frac{EI}{mL^3}}$$

$$\frac{1}{N_{cr}^2} = \frac{1}{N_s^2} + \frac{1}{N_1^2} + \frac{1}{N_2^2} + \cdots$$

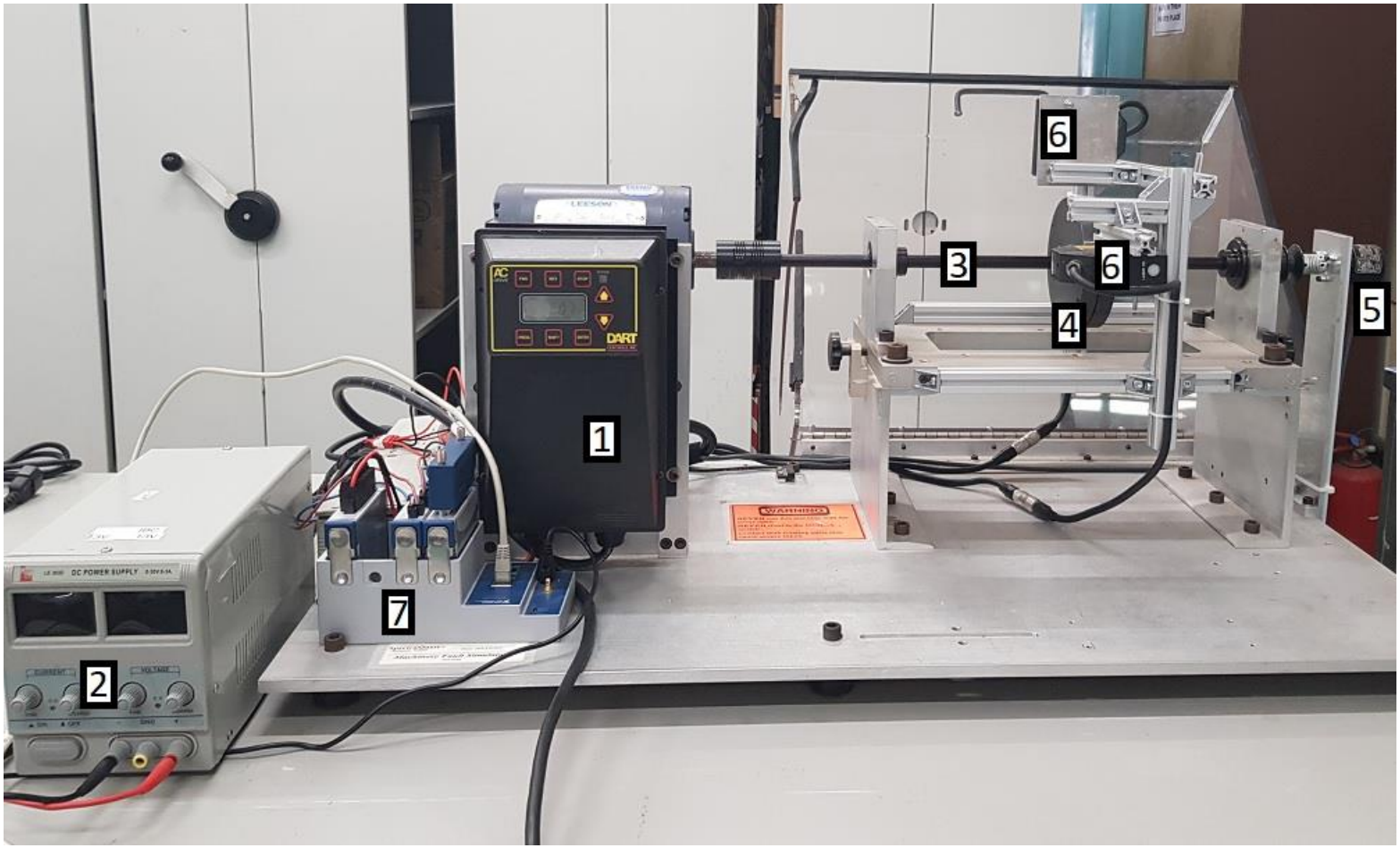
Dunkerley's Method

Experimental Test Bench - Rotordynamics

- Tool to study failures without compromising machines
- Components machined to high tolerances and system has sufficient damping – can operate at resonance
- Mass can be added, removed or repositioned simply
- Delivers experience in vibration

SQi SpectraQuest, Inc.

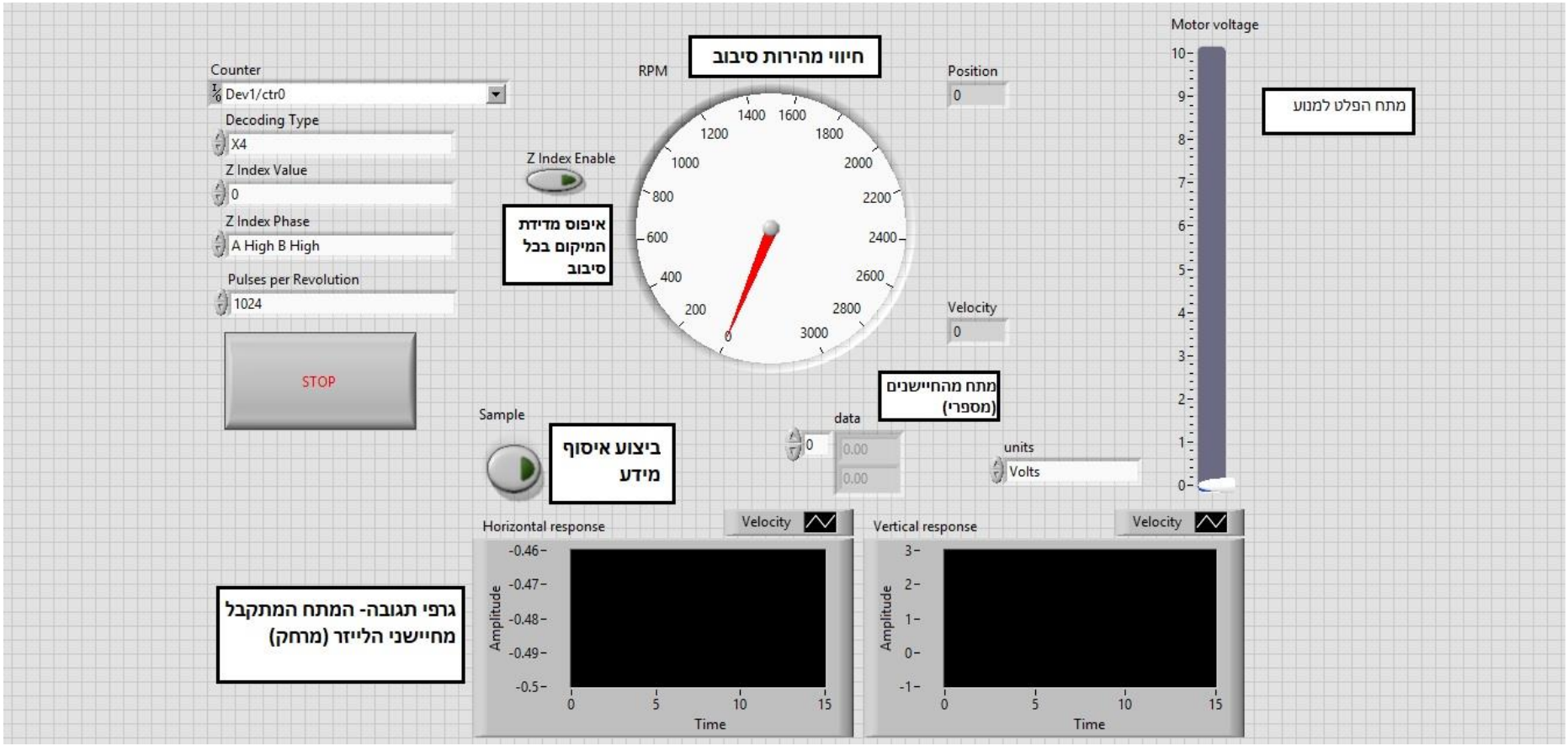
Experimental Test Bench - Rotordynamics



1. Motor and controller
2. DC power supply
3. Aluminum shaft
4. Disks\Masses
5. Incremental encoder
6. Displacement sensors
7. Data acquisition
8. Stroboscope

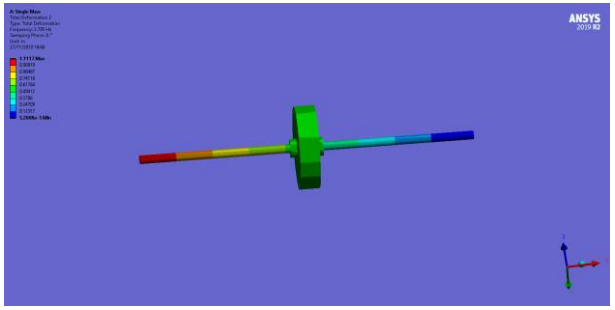
Experimental Test Bench - Rotordynamics

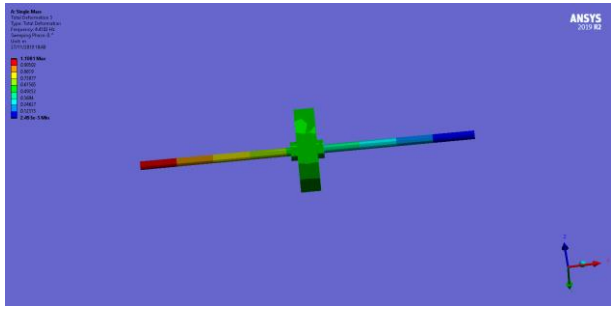
In house LabVIEW code

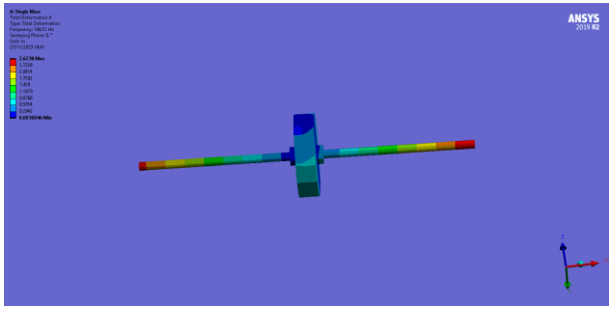


Student Tasks

- Class quiz
- During the experiment
  - Sensor calibration
  - Recording data for different mass locations **while in resonance**
- Final report
  - Comparison of measurements to analytical solution
  - Rotodynamic simulation (Ansys or MATLAB)
    - Finding mode shapes and comparison to experimental findings
    - Plotting Campbell diagram
- Discussion - results and conclusions

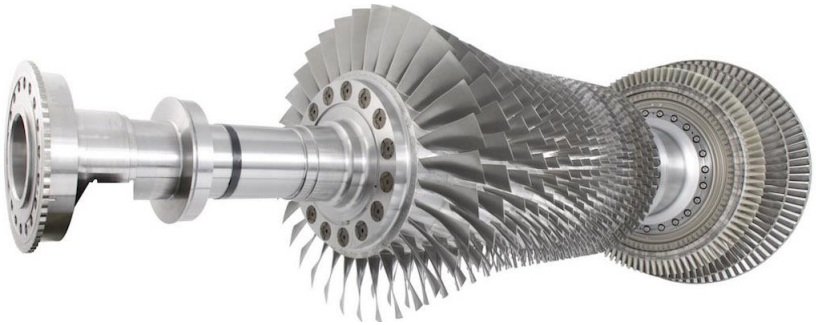


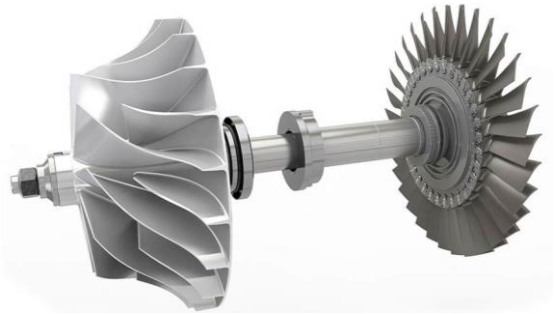




Balancing Background

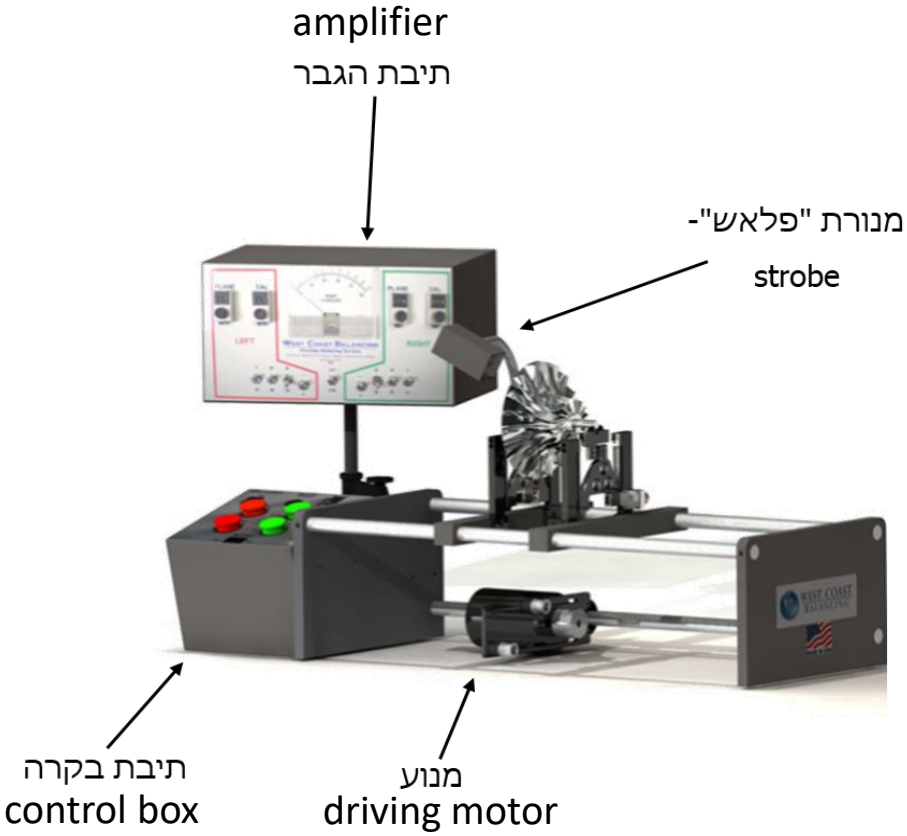
- Rotating systems in balance do not generate centrifugal forces
- In order to reach such state, rotating system must undergo balancing
- Balancing done by adding or removing mass
- Each rotating component has allowed tolerance as defined by manufacturer
- System balancing is checked and done using special balancing machines



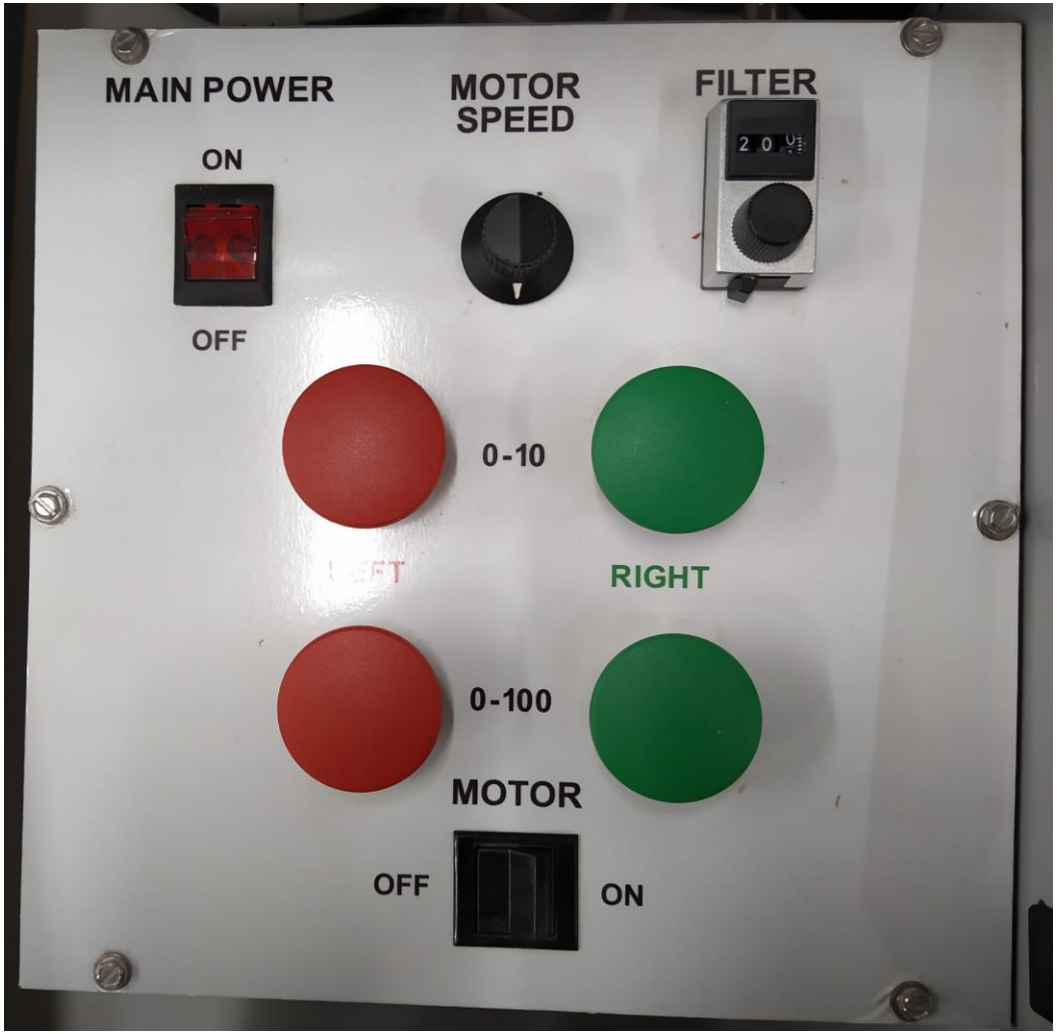


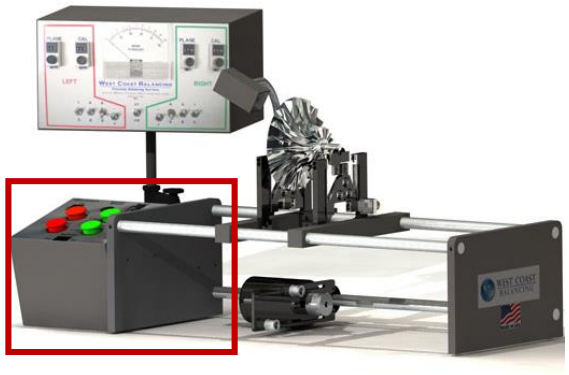
Experimental Test Bench - Balancing

- WCB-30 "Soft-Bearing" machine
- To simplify balancing process for students, mass is added rather than removed
- Rotor sits on bearings and is connected to accelerometers
  - Rotation generated by motor
- Strobe provides data on imbalance phase
  - Relationship between reference point on rotor and imbalance location
- Combination of both readings yields amount of imbalance and location to add\remove mass



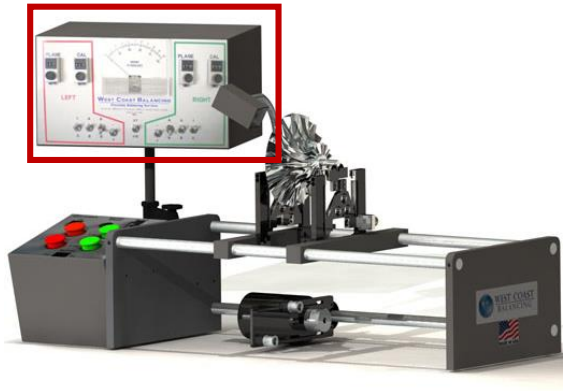
Experimental Test Bench - Balancing





Control Box

Experimental Test Bench - Balancing



Amplifier

Student Tasks

- Class quiz
- During the experiment
  - Students receive dissembled SR-30 micro gas turbine and assemble it according to manual
  - Rotor stage is balanced by addition of mass
- Final report
  - Including general questions on micro gas turbine components and design considerations
  - Description of balancing process and involved methodology

Thank you for your attention!

Special thanks to Prof. Izhak Bucher and the staff of Dynamics and Mechatronics Laboratory of Mechanical Engineering Faculty