INVESTIGATION OF THE CRITICAL ROTATION SPEED OF A ROTOR ON NON-LINEAR SUPPORT

D.Lior, I. Leschinsky

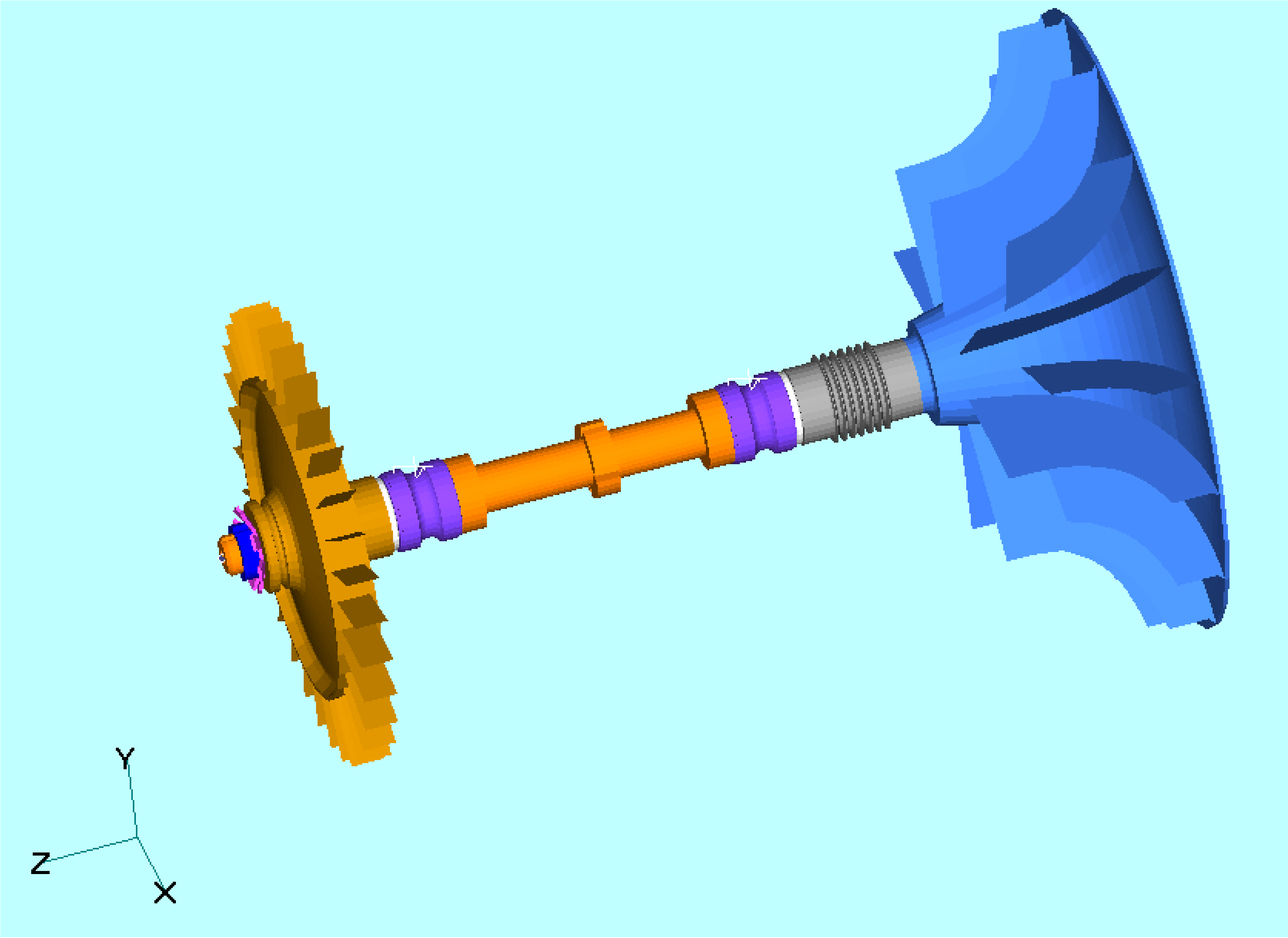
When the critical rotation speed of a flexible rotor lies within the working rotation speed margins, crossing it becomes a major problem for the flexible rotor's operation.

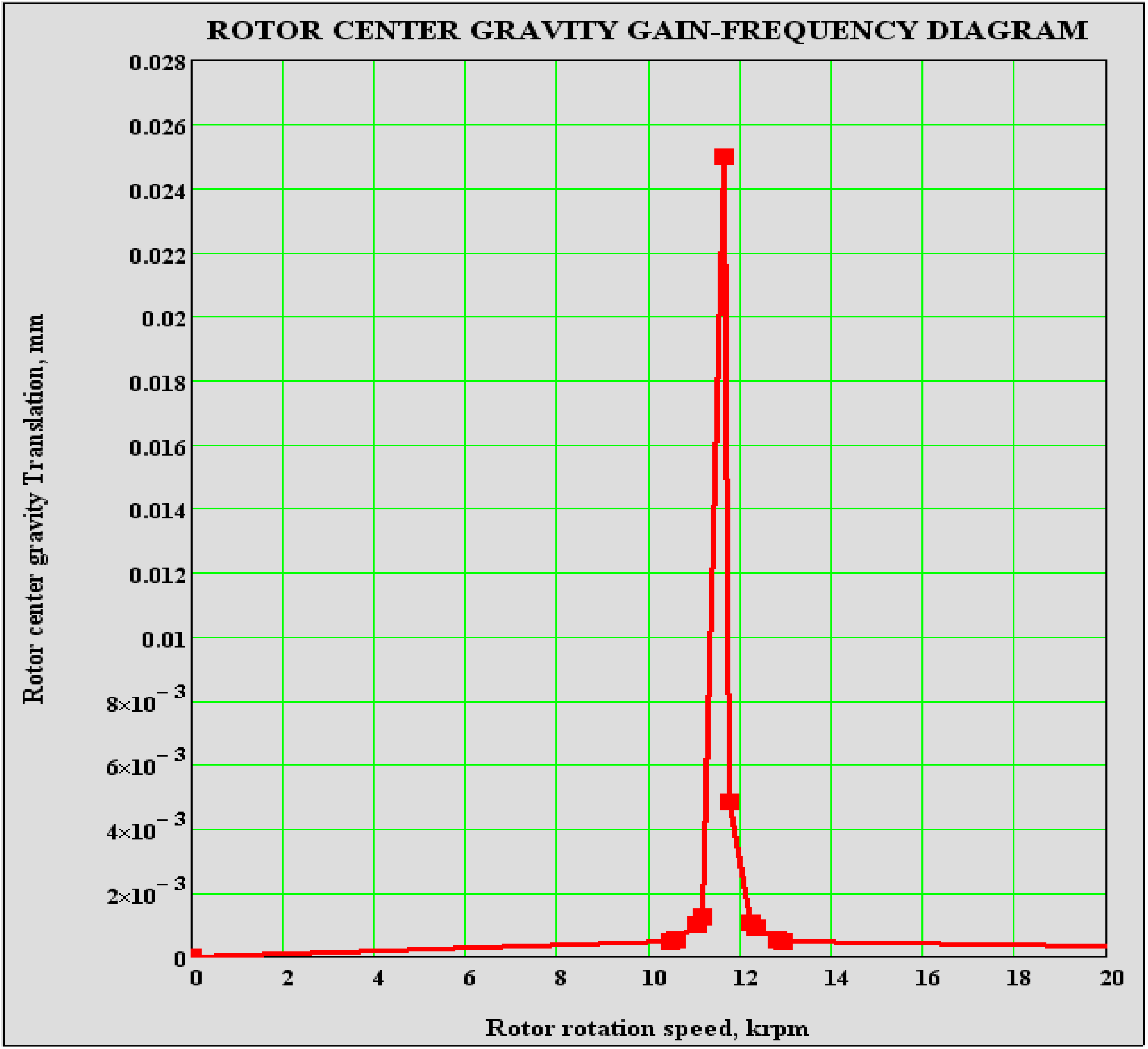
The system investigated below is a rotor with two supports having a critical rotation speed within the working range.
The system is shown in **slide 3.**
First a simulation was performed for the system being supported by ball bearings only, without elastic rings around them.

The stiffness of the supports is the radial stiffness of the bearings.
A damping ζ=0.01 was assumed.

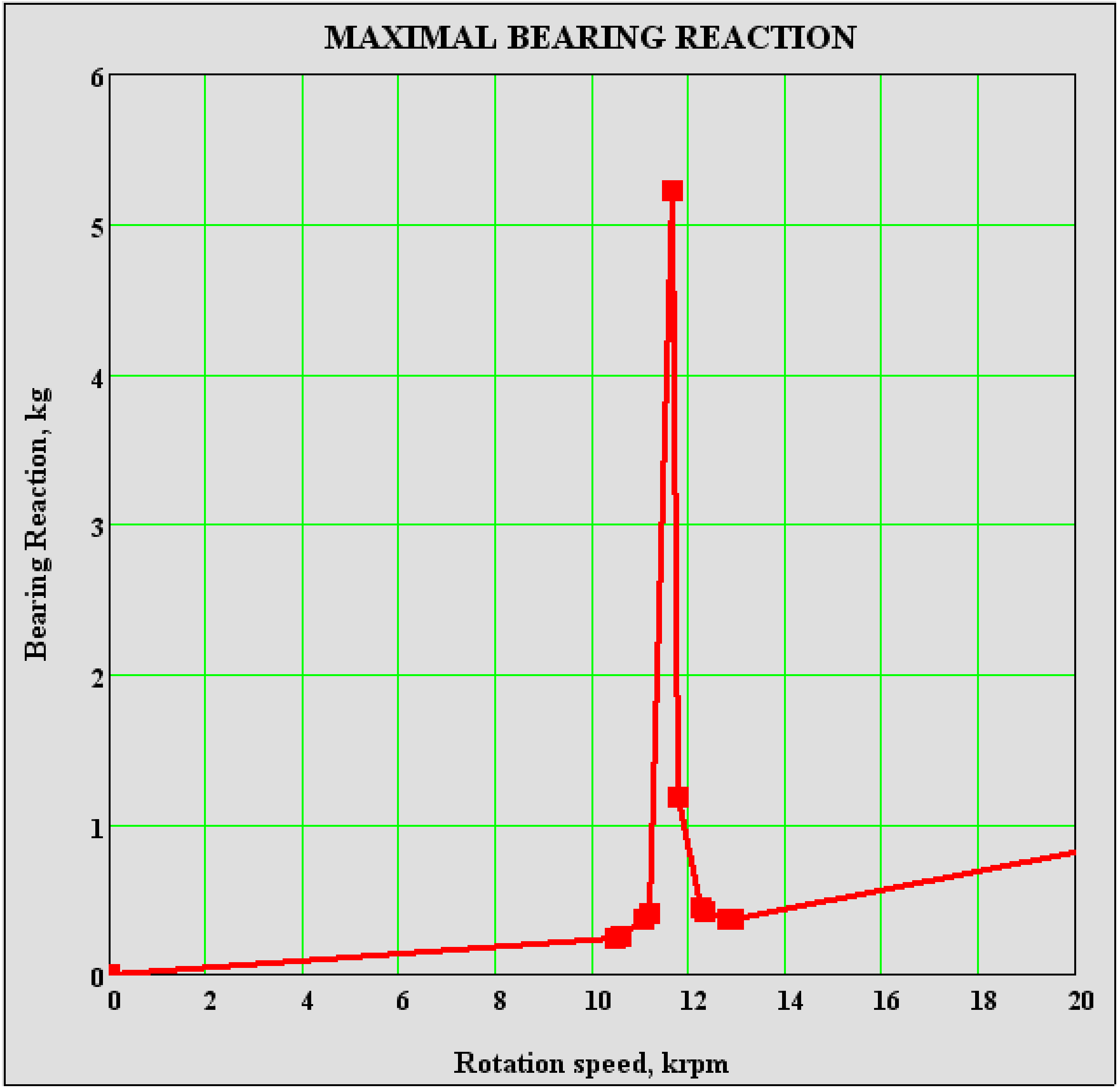
Following this simulation, the rotor's center of gravity frequency response graph was constructed.
The frequency response diagram of the c.g. is shown in **slide 4**.

The maximal bearing reaction, when in resonance, is 5kgf.
This can be seen in **slide 5**.


Y
Z
X



ROTOR CENTER GRAVITY GAIN-FREQUENCY DIAGRAM
Rotor center gravity Translation, mm
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
8×10⁻³
6×10⁻³
4×10⁻³
2×10⁻³
0
0
2
4
6
8
10
12
14
16
18
20
Rotor rotation speed, krpm


MAXIMAL BEARING REACTION
Bearing Reaction, kg
Rotation speed, krpm
0
1
2
3
4
5
6
0
2
4
6
8
10
12
14
16
18
20

The simulation was performed using MSC\Nastran for Windows. In this software package, it is not possible to perform a rotor dynamics analysis. Therefore, the bearing reactions were calculated by formula. The formulae used for the calculation of the bearing reactions are:

TOTAL FORCE ON SUPPORTS FROM REVOLVING ROTOR

$$Q_i = (e_o + T2_i) \cdot M \cdot \omega_i^2$$

Where

e_o - Residual specific unbalance (e_o = Unbalance / Rotor Weight)
$T2_i$ – Rotor center gravity translation under unbalance
M - Rotor mass
ω_i - Rotor rotating speed

SUPPORT REACTION

$$R1_i = \frac{L}{l} Q_i ; R2_i = Q_i - R1_i$$

$$R2_i < R1_i$$

Where

L and l are Rotor Geometrical Parameters:

L-maximal distance between Rotor center gravity and support

l – distance between bearings

Operation with a 5 kgf load is not possible : when in resonance the center of gravity oscillates at 20 mm/s. This value is too high for the system in question.

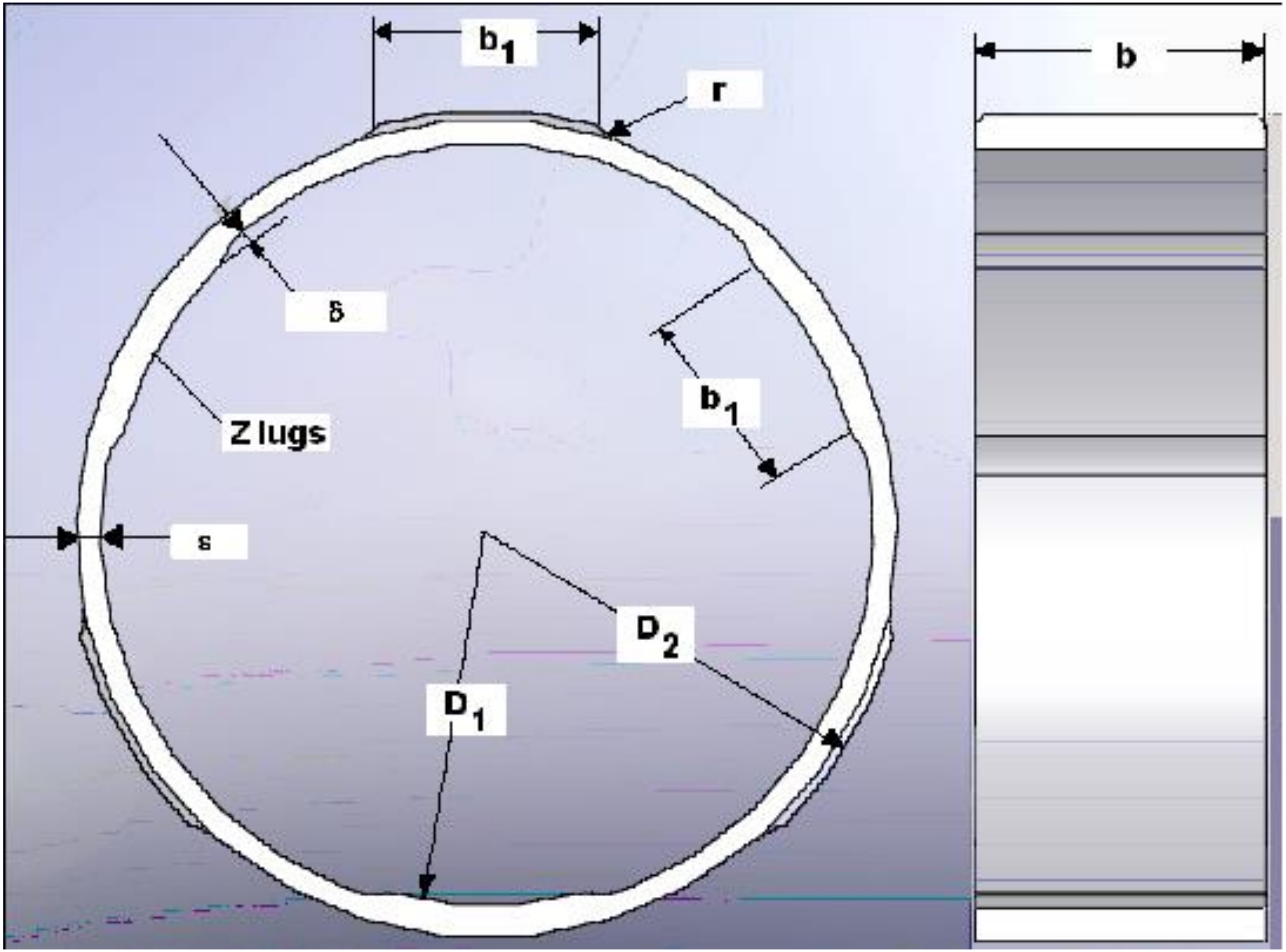
Our goal is to go through the resonant frequency. For this purpose, elastic rings, known as **Allisson's dampers**, are fitted around the bearing.

As a rule, the bearing with the highest reaction load is the bearing fitted with an **Allisson's damper**.

Those elastic rings have alternating internal and external protuberances.

An **Allisson's damper** is shown in the figure in ***slide 9***.

ELASTIC RING



With the geometry of the ring know, its stiffness can be calculated.

The formula for the **Allisson’s damper** radial stiffness is*:*

$$\frac{1}{k}=\frac{(D_{av}-0.3\cdot b_1\cdot z)^3}{0.129\cdot b\cdot E\cdot z^4\cdot s^3}\cdot\{1-[1-\frac{s^3}{(s+\delta)^3}]\cdot(1.45\cdot A-0.9\cdot A^2+0.2\cdot A^3)\}$$

Where

$$A=\frac{(b_1+\sqrt{2\cdot r\cdot\delta})\cdot z}{D_{av}}$$

K – Elastic Ring radial stiffness

The Precision of the formula is 1.5-5.0 %

A simulation for the system equipped with an Elastic ring (as described above) was performed.

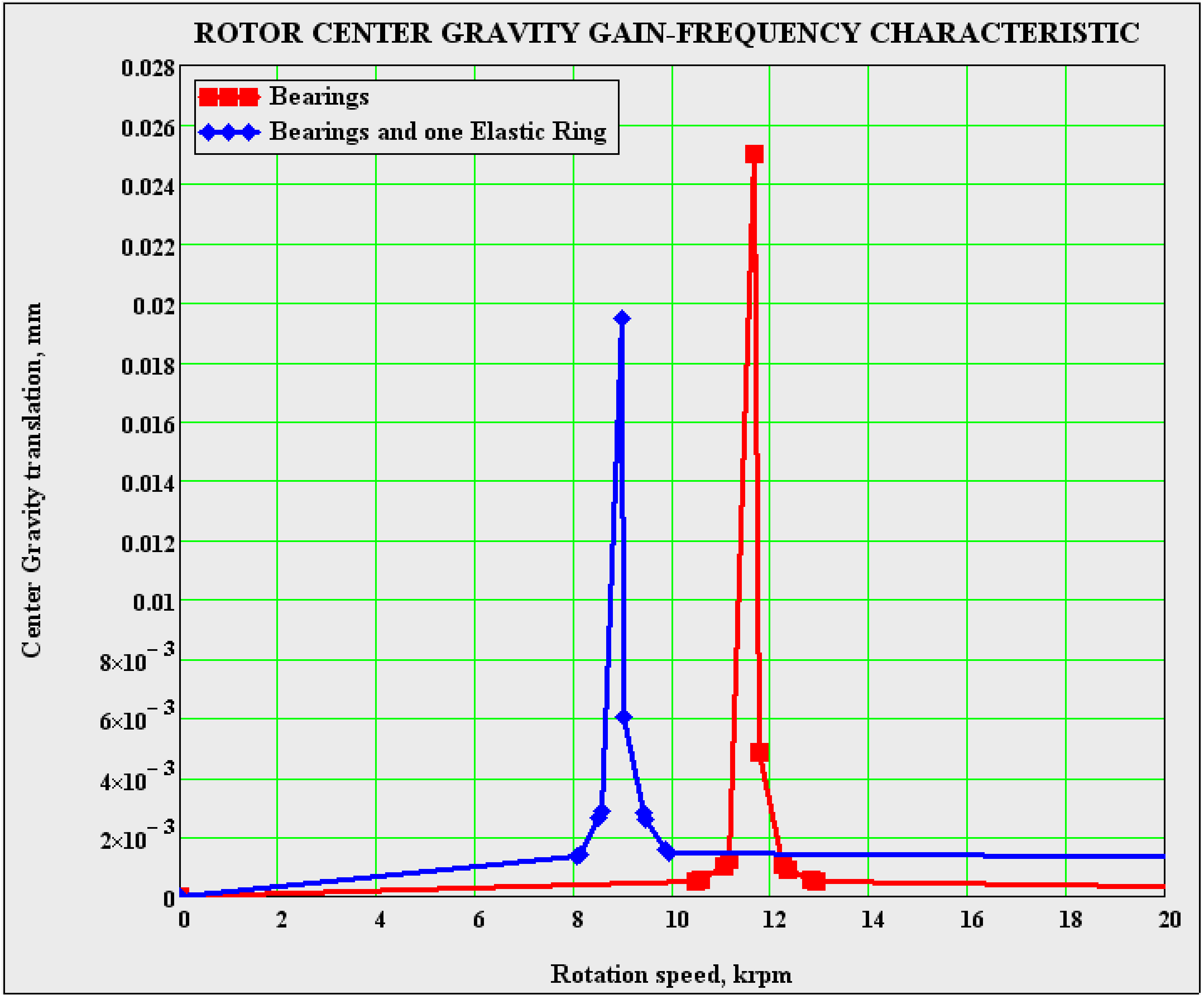
In this case, the damping used is $\zeta=0.05$.

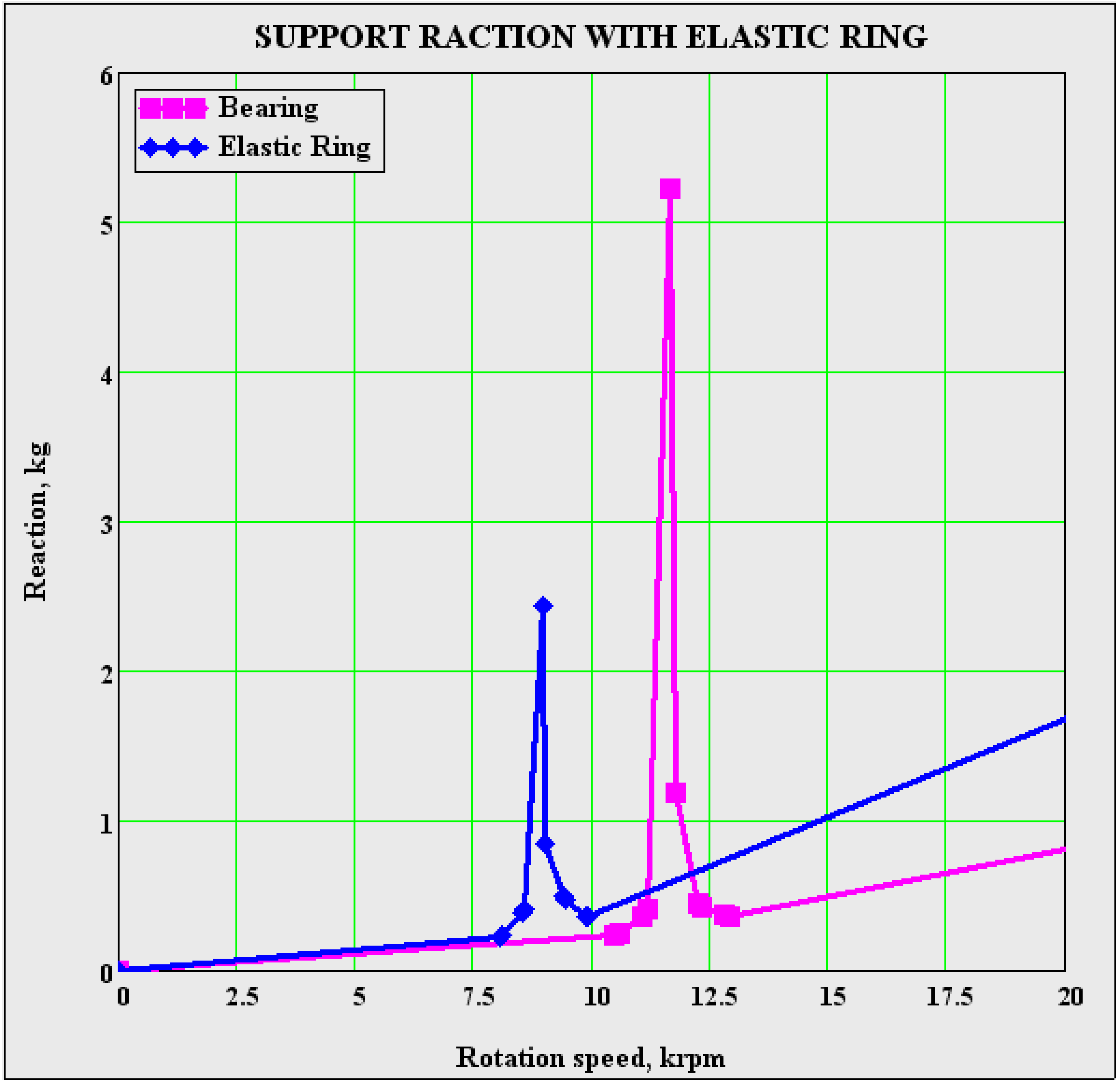
The damping of the system with an elastic ring is higher than the damping of the system without the elastic ring, because adding elements (such as an elastic ring) to a system increases the friction. This leads to more energy losses, and as a consequence to a higher damping .

The simulation does not take the gyroscopic effect into account, because it is of no interest to the subject of this study.

The frequency response is shown in **slide 13** and the maximum support reaction in **slide 14**.

With the addition of the elastic ring, the critical rotation speed and the maximum support reaction become lower.


ROTOR CENTER GRAVITY GAIN-FREQUENCY CHARACTERISTIC
Bearings
Bearings and one Elastic Ring
Center Gravity translation, mm
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
8×10⁻³
6×10⁻³
4×10⁻³
2×10⁻³
0
0
2
4
6
8
10
12
14
16
18
20
Rotation speed, krpm


SUPPORT RACTION WITH ELASTIC RING
Bearing
Elastic Ring
Reaction, kg
Rotation speed, krpm
0
1
2
3
4
5
6
0
2.5
5
7.5
10
12.5
15
17.5
20

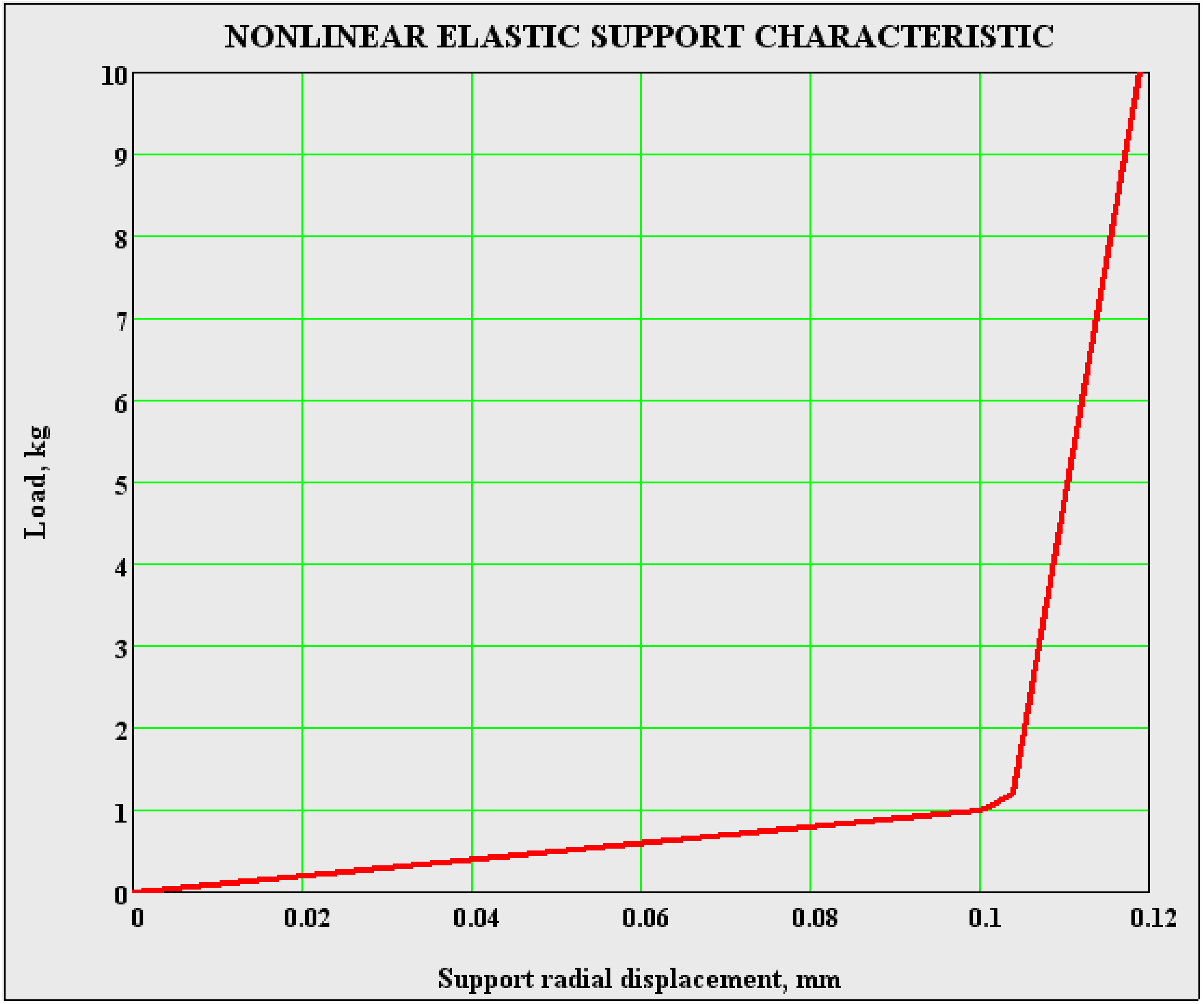
After we placed an elastic ring around the bearing, the stiffness of the support became nonlinear.

The nonlinearity of the support stiffness can be seen in the figure in **slide 16**.

In the **<u>first segment</u>** of the graph in **slide 16**, the support has the combined stiffness of the bearing and of the elastic ring.

In the **<u>second segment</u>** the support has the stiffness of the bearing only.

The transition between the stiffness of the bearing and the ring together to the stiffness of the bearing only **occurs** when the **gap closes** and the elastic ring stops being active.


NONLINEAR ELASTIC SUPPORT CHARACTERISTIC
Load, kg
10
9
8
7
6
5
4
3
2
1
0
0
0.02
0.04
0.06
0.08
0.1
0.12
Support radial displacement, mm

Crossing the Resonant Frequency

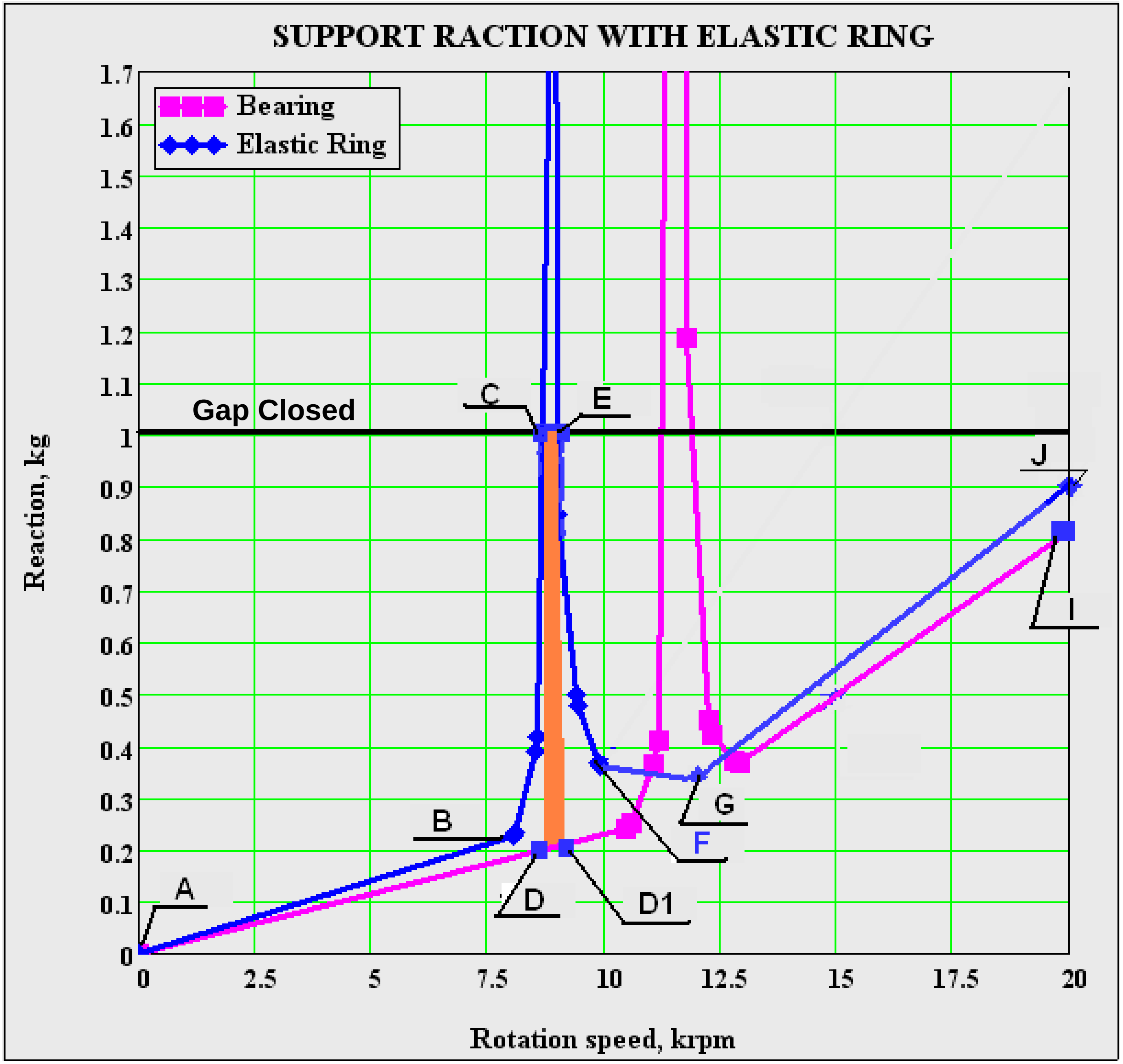
Refer to the figure in **slide 19**.
The rotor starts operating, supported by the ring with a low stiffness.
The amplitude of the support reaction is not higher than the blue line: **A-B-C**.

At the point **C**, the gap closes, (the elastic rings becomes ineffective) and the amplitude of the support reaction goes down, until the **pink line (D-D1)**, and the support stiffness is equal to the stiffness of the bearing without the elastic ring.

After the **point E**, the amplitude of the support reaction is not higher than the **line E-F-G-J (blue**)

In the **zones ABCD and EDHGJ**, the simulation is a **simple** linear study.

In the **zones CDD1E** the stiffness is nonlinear
and the simulation is much more complicated.



Magnitude of the Maximal Reaction as Rotation speed Function:

curve ABC ->

-> CDD1E zone->

-> curve EFGJ

Conclusion

If elastic rings, such as Allisson's dampers are used, it is possible to get a rotor with very low support reaction when in resonance.