O. Fomina chief designer, NPO “Saturn”

N. Kikot compressor division head, NPO “Saturn”

M. Leontiev Professor of Moscow aviation Institute

# Active Control of Rotor System Supports

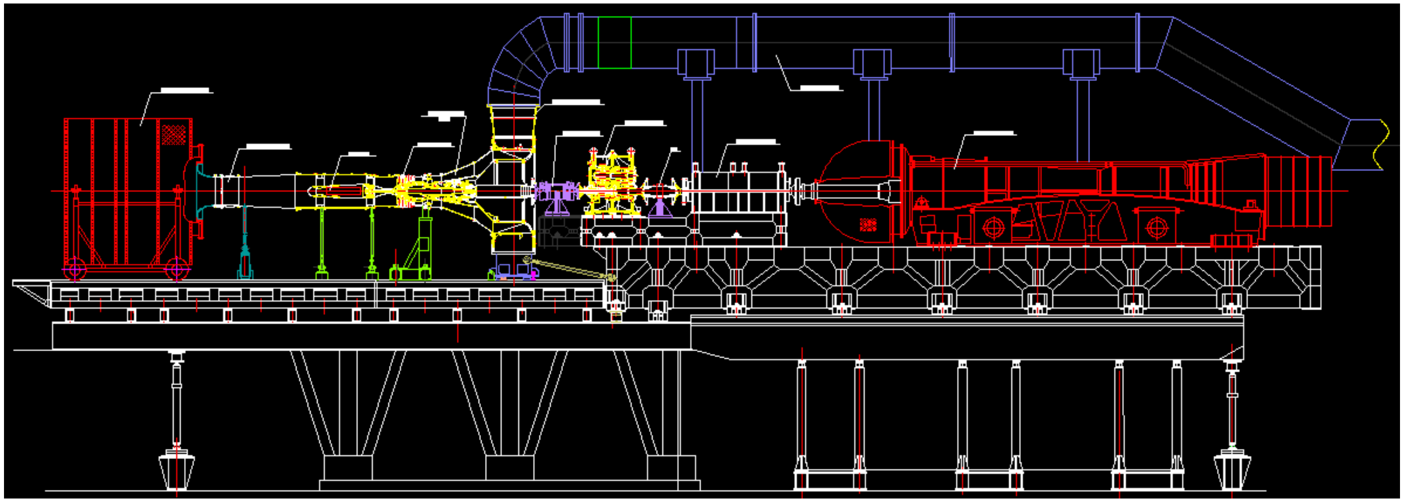
САТУРН

НАУЧНО-ПРОИЗВОДСТВЕННОЕ ОБЪЕДИНЕНИЕ

TRANZIT

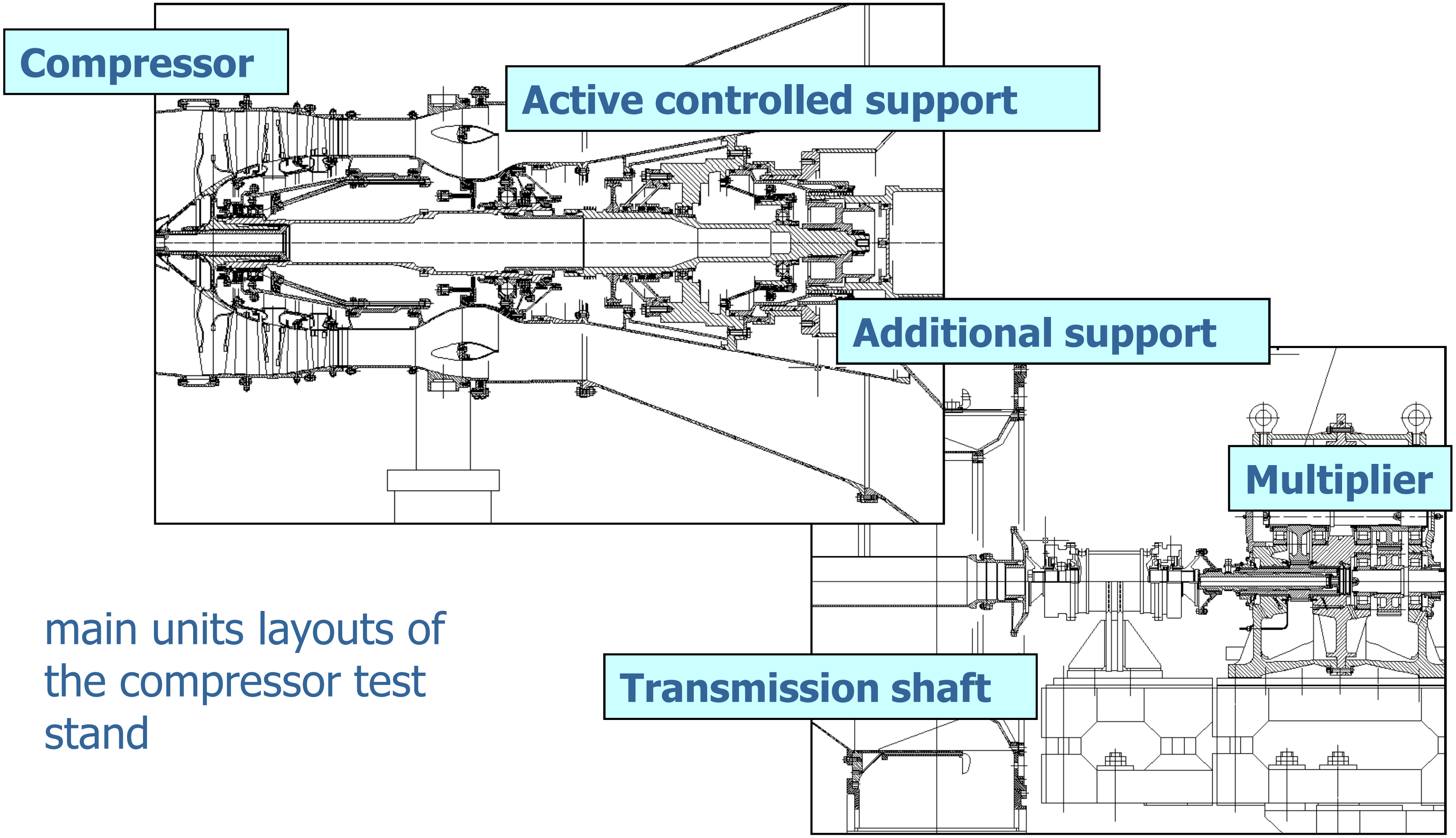
# Compressor test rig layout

Compressor and fan test stands are widely used in design and development of modern Gas Turbine Engines. The test procedures include wide ranges of operating speeds. This operating requires avoidance of the transmission rotor critical speeds. The problem may find its solution in the gearbox tuning or the elements replacement but this approach is expensive and time consuming. Also the wide range of speeds does not allow introduction of flexible damping supports because often the operating includes the both first and second critical speeds. The resulting vibrations hurt the facility reliability and life.



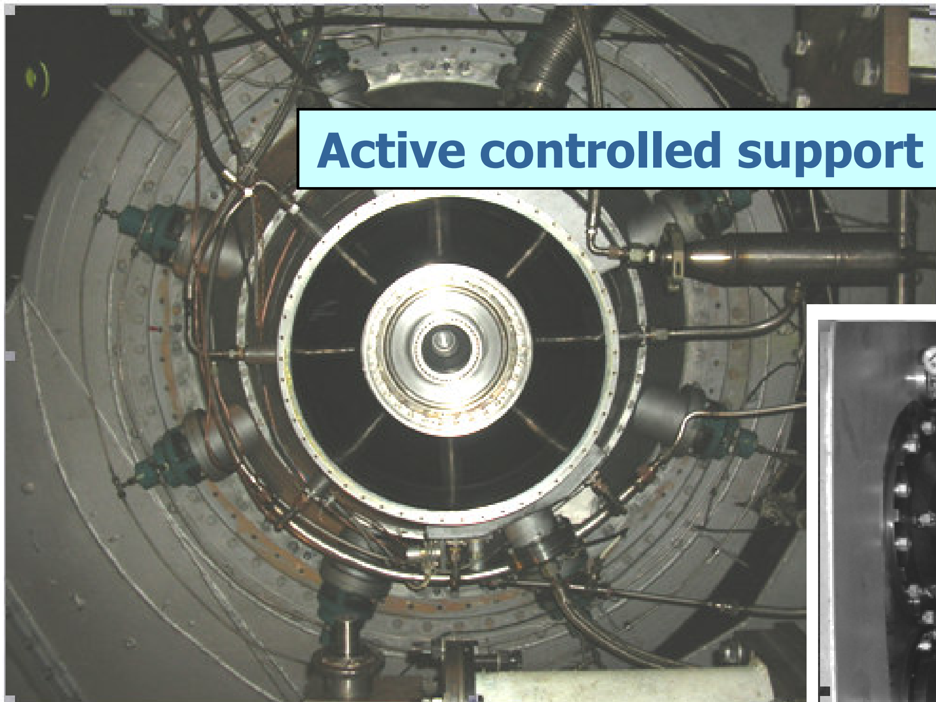
It is possible to solve the problem by introduction of **supports with controllable stiffness properties**. This approach provides the option of the support flexibility tuning during the test stand operation and thus to change the critical speeds and remove them from the operating speed.

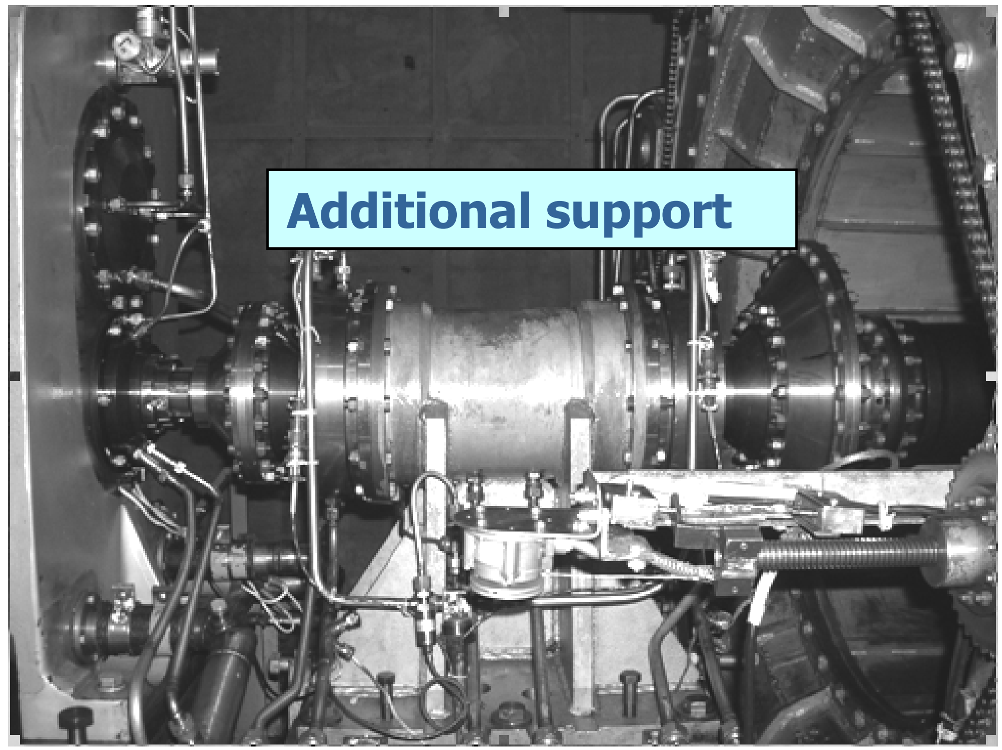
# Test rig units




main units layouts of the compressor test stand

# Test rig hardware pictures



# Modeling of test rig rotor dynamical structure

Test stand modifications were supported by modeling of rotor structure. The rotor was modeled with the program Dynamics R4.2. (Alfa-Tranzit Co.,Ltd) the two models of the test stand:

Rotor model of test test stand without IS

Rotor model of test stand with IS

These model includes just-listed units

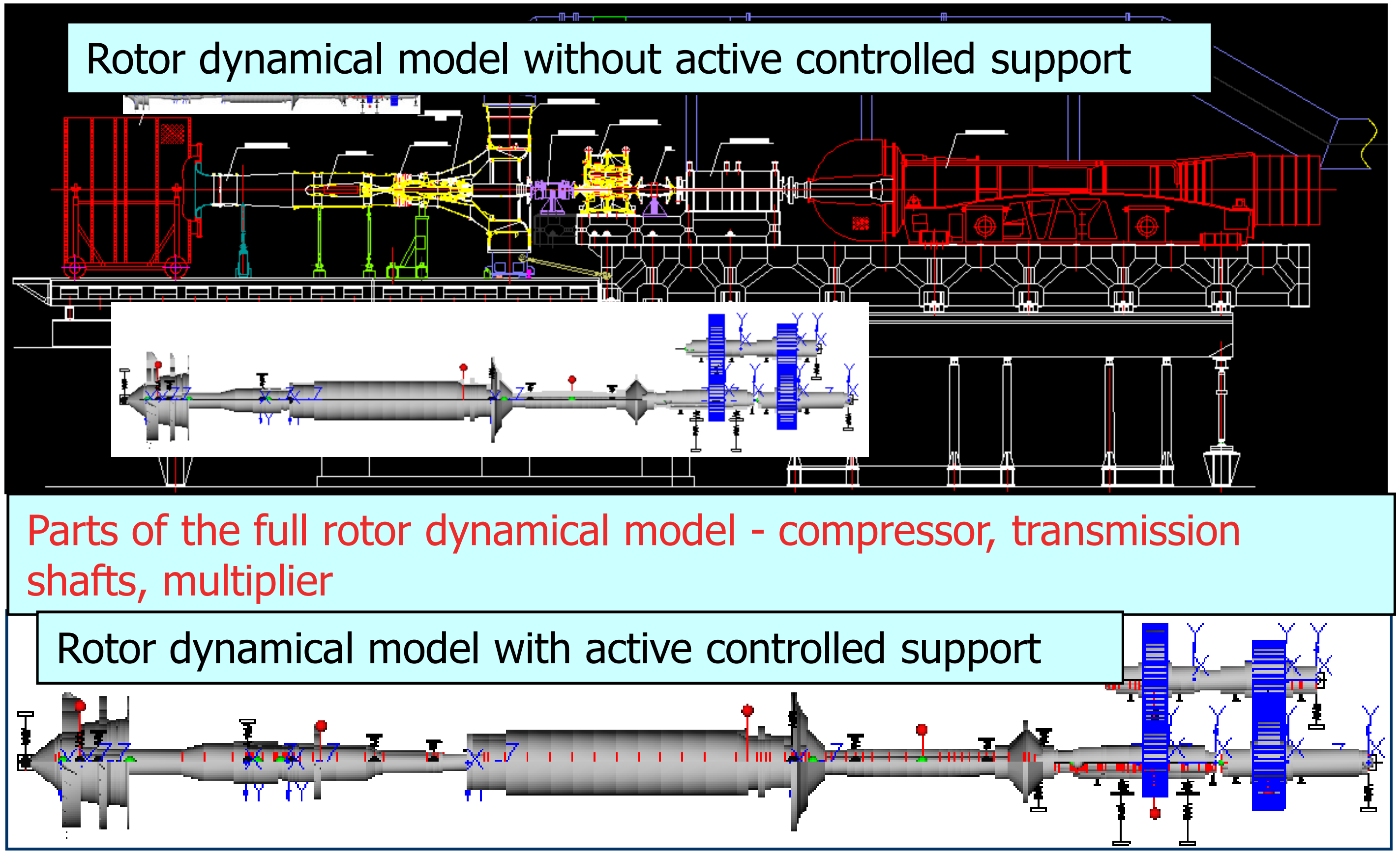
Tested unit - compressor

Transmission shafts

Intermediate support

Additional support

Multiplier



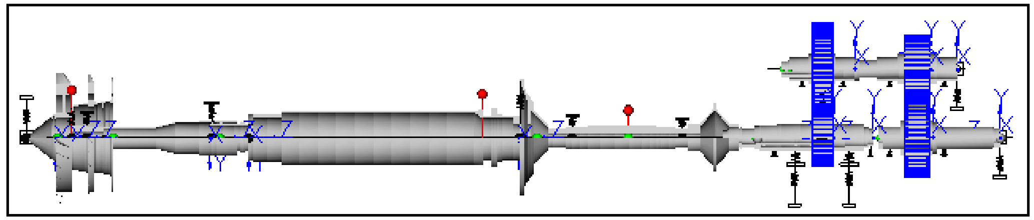

It is necessary to note that models do not include housings. Nevertheless the good results were obtained with these models.
Experimental data were used for the validation of the rotor models.

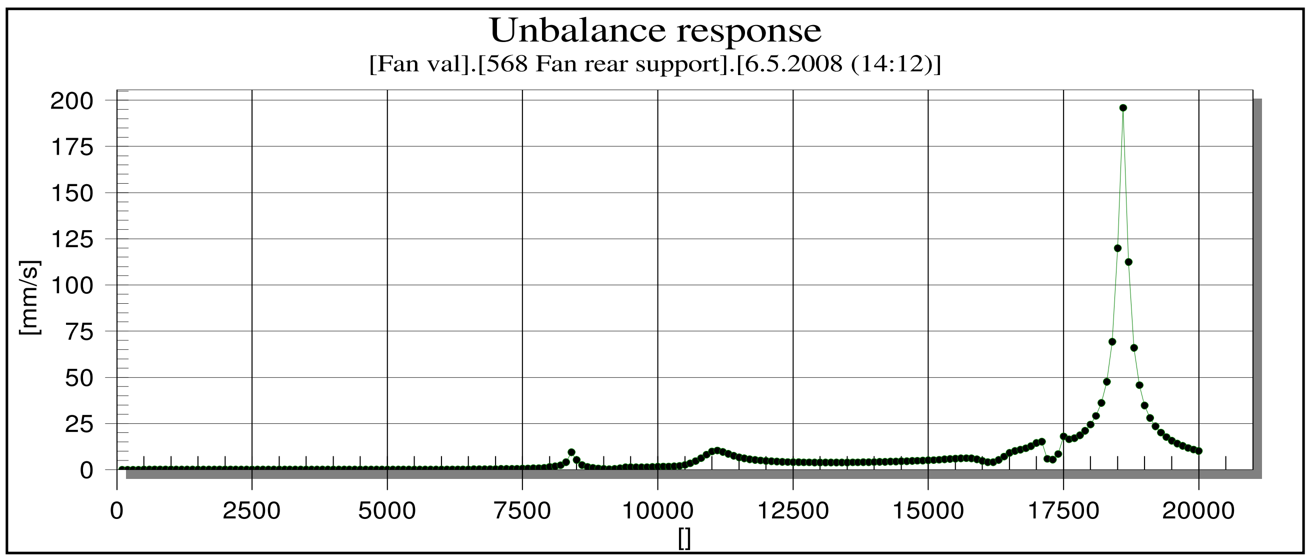
САТУРН НАУЧНО-ПРОИЗВОДСТВЕННОЕ ОБЪЕДИНЕНИЕ

TRANZIT

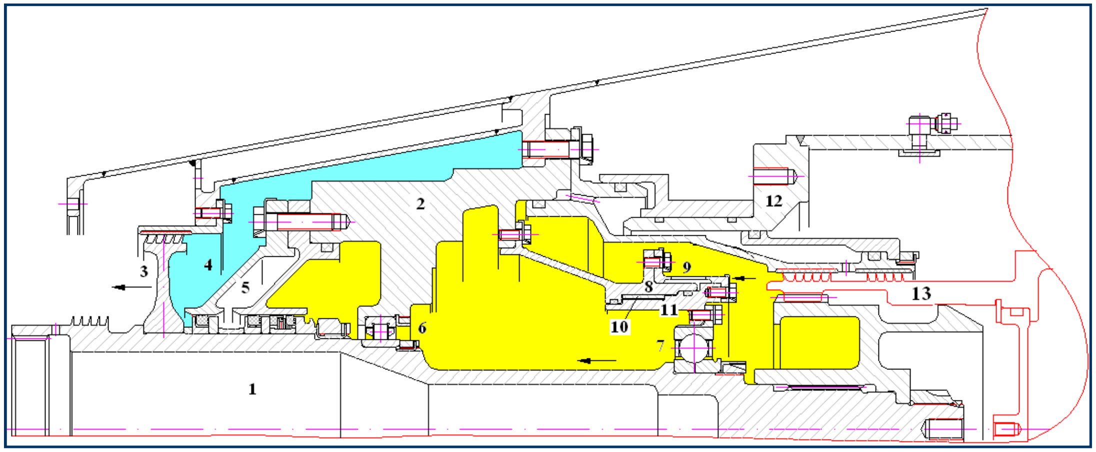
# Model without support with active control

Model analysis of the initial test stand structure (without IS) showed that there is a critical speed with a large vibration level in the operating range (the level is about 200 mm/sec).
It is clear that a transition of that critical speed can not be effected.





# Layout of support with active controlled flexibility




Specific features of the support are **flexible elements** that change the support flexibility and **the control air chamber**

When the control air pressure is absent the support load is shared between the two flexible elements and the support stiffness is determined by the elastic ring and the "squirrel cage" coupled in parallel.

The control air pressure produces an axial load applied to the intermediate support shaft (1) shown with the arrow in picture. The ball bearing (7) transmits the load to the "squirrel cage". The axial load turns "squirrel cage" face against the opposite one and reduces the element length for 0.25…0.3 mm (see the arrow). The length reduction moves the shaft, the bearing and it's housing (11). The movement excludes the gap between the ring contact surface (8) and the bearing housing surface, This excludes the flexible elements' degree of freedom and the support rapidly changes its stiffness.

The radial load is taken by stiff elements of the support and the support flexibility grows sharply.

1– shaft of the intermediate support; 2– case of the intermediate support; 3- disk of the labyrinth control of the pressure control cavity; 4- cavity of the pressure control; 5- block of the contact seals; 6- roll bearing; 7- ball bearing; 8- case of the ball bearing; 9– "squirrel case"; 10– elastic ring; 11- case of the bearing; 12– internal case of the intermediate support air cavity ; 13- shaft of the multiplier

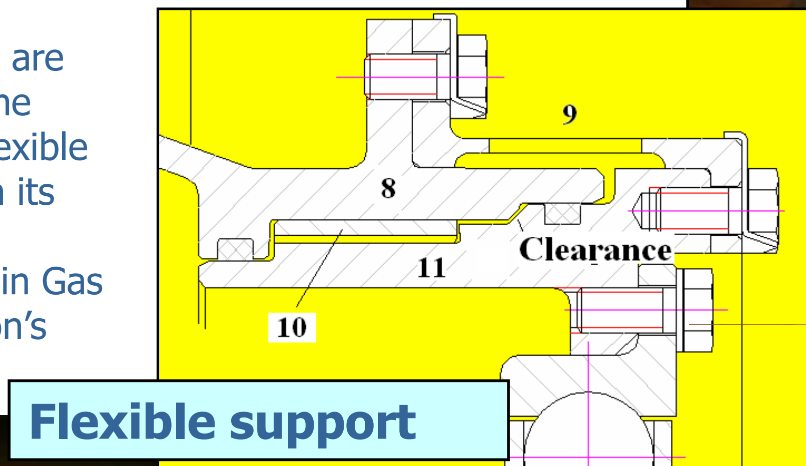
САТУРН
НАУЧНО-ПРОИЗВОДСТВЕННОЕ ОБЪЕДИНЕНИЕ

TRANZIT

# Support construction with the variable stiffness

**support with controllable stiffness properties** includes two flexible elements and the gap (~0.25 mm).

The flexible elements are the flexible ring and the "squirrel cage". The flexible ring with 10 ledges on its both sides is a typical structure widely used in Gas Turbine Engines (Alison's ring).

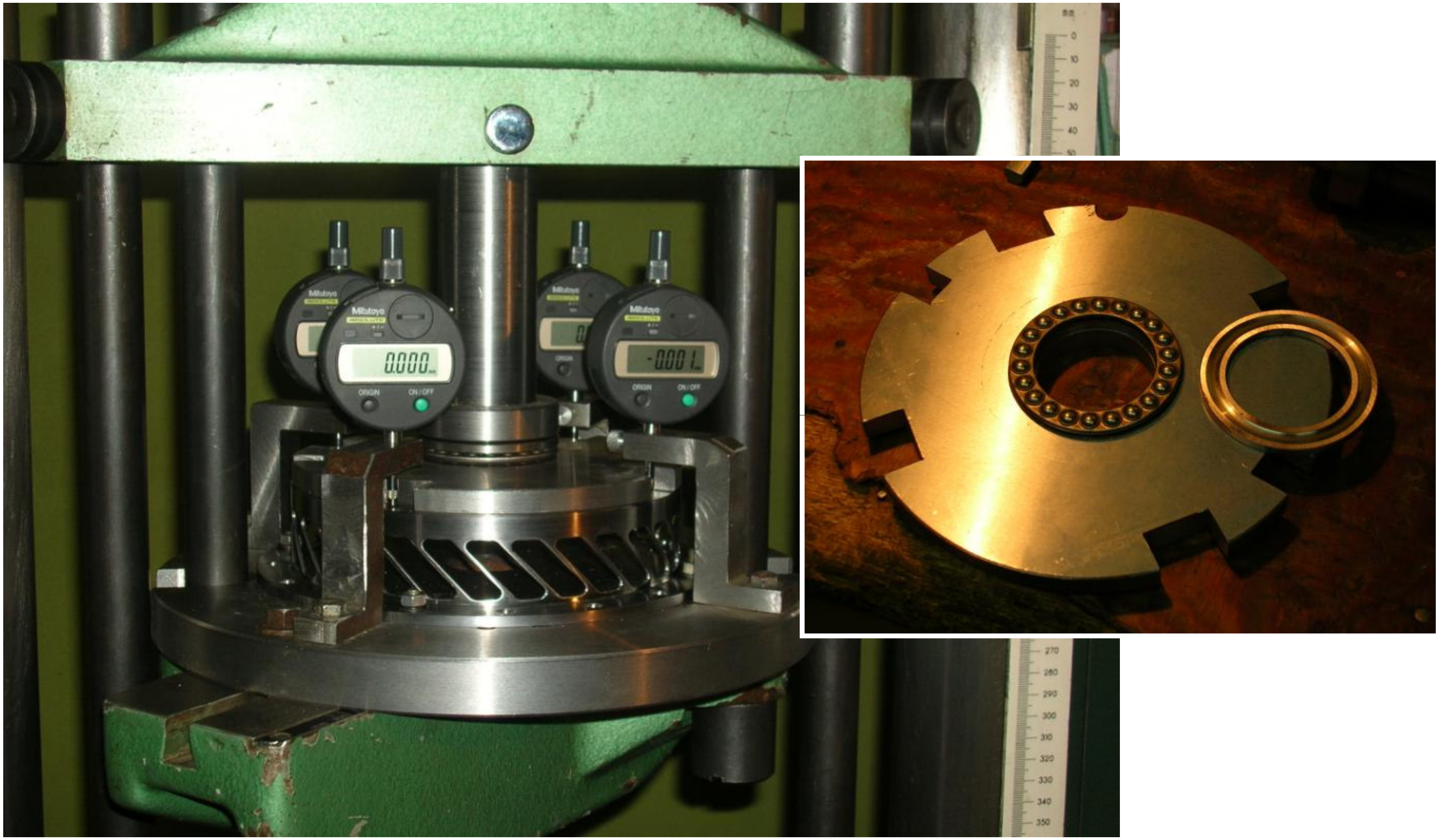


The ring volume is supplied with oil.

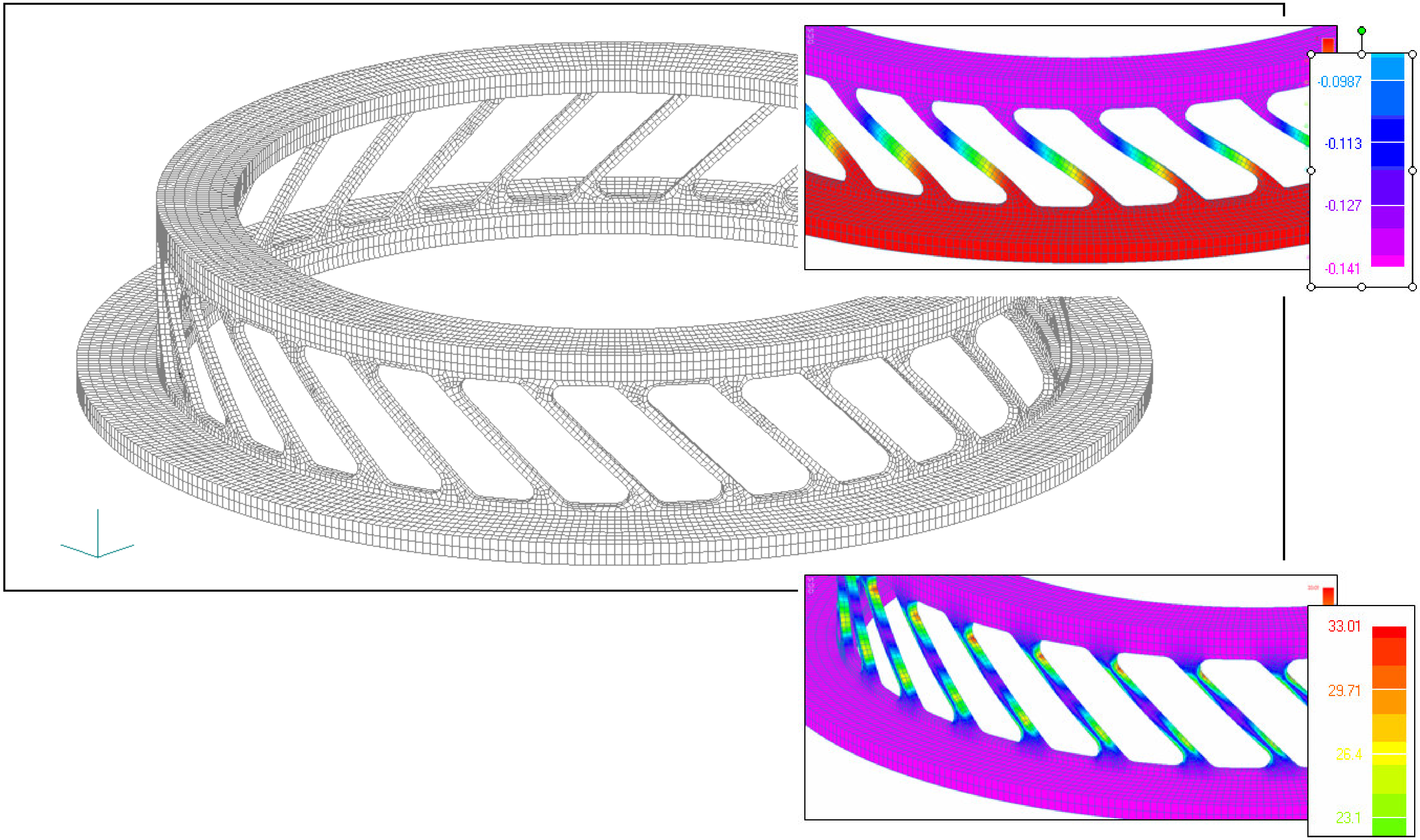
The "squirrel cage" has a set of lengthwise slots 45 degrees inclined from their generatrix.

The total flexibility is selected as to exclude resonance modes in the operating range of speeds.

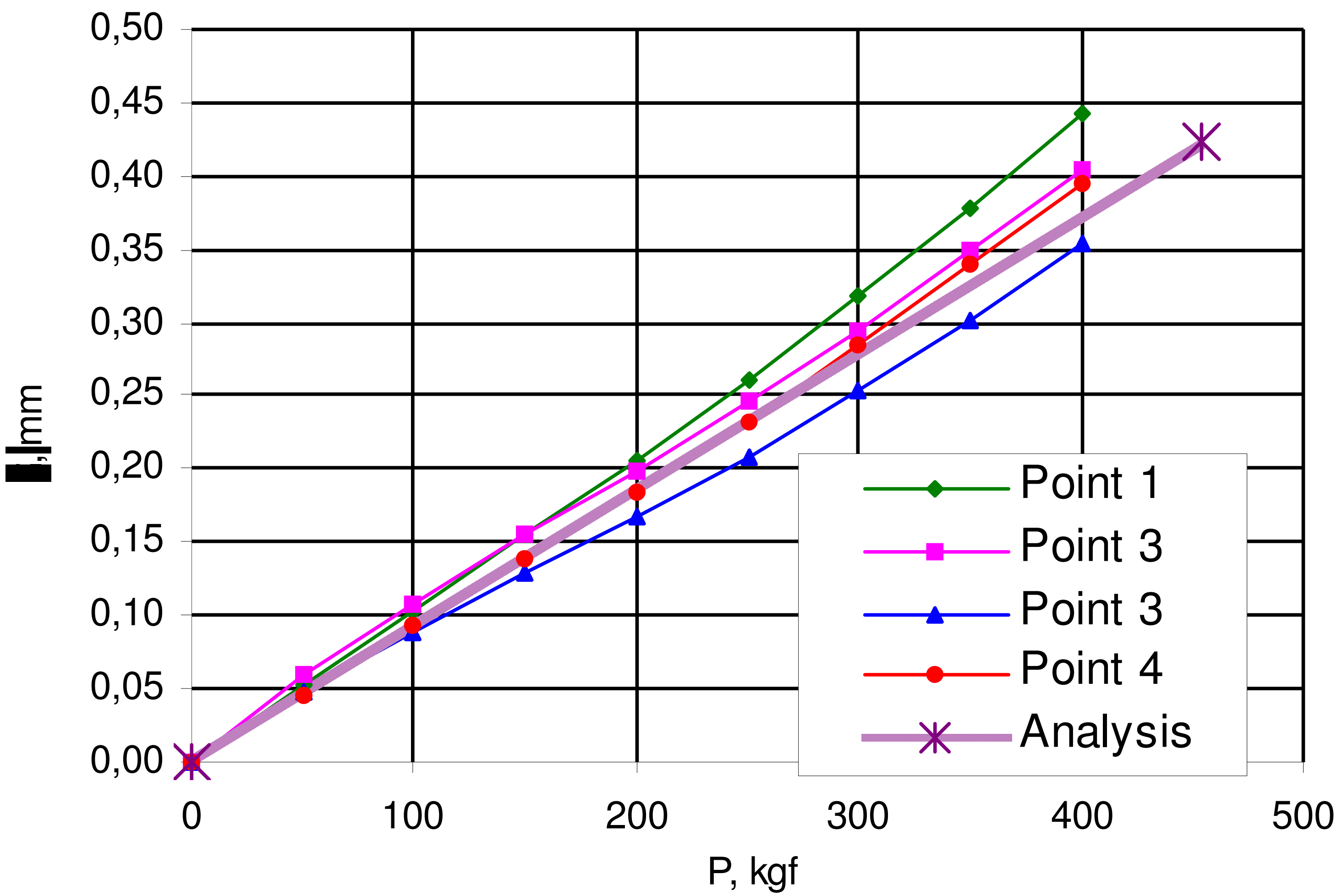
# Test rig for static loading and trust ball bearing



# Squirrel cage FE model and simulating results

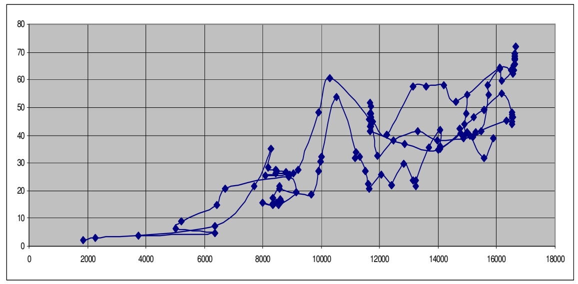


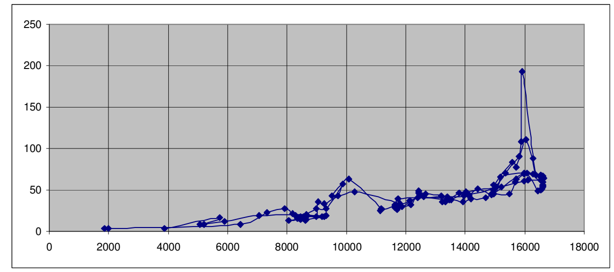
# Test and analytic results (static loading)

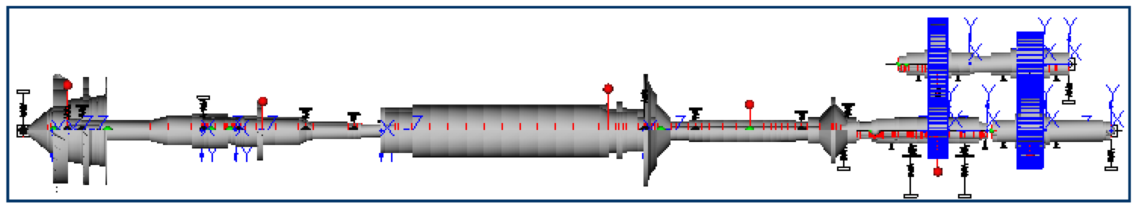


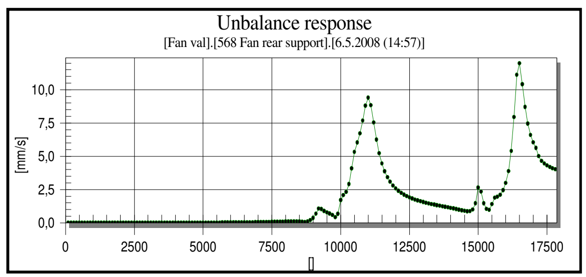
# Test and analytic results

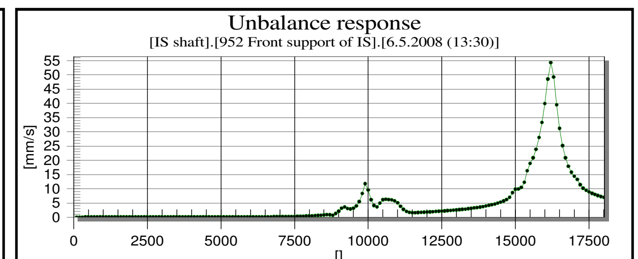
**Compressor support vert** **Intermediate support vert**






Analytic and test results of the rotor structure dynamic response with **soft intermediate support** are given at this slide.

The control air pressure is absent so the stiffness of the intermediate is determined by the elastic ring and the "squirrel cage" coupled in parallel (**soft support**).

The results are given for the two points – compressor accelerometer and intermediate support accelerometer.

You can compare locations of resonances.

The simulation results are in a good comparison with the test results.

САТУРН
НАУЧНО-ПРОИЗВОДСТВЕННОЕ ОБЪЕДИНЕНИЕ

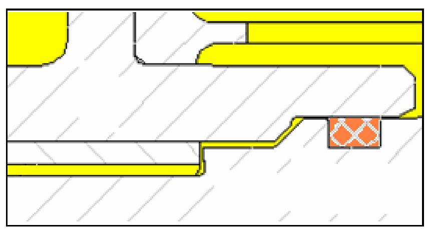
TRANZIT

# Comparing of analytic results

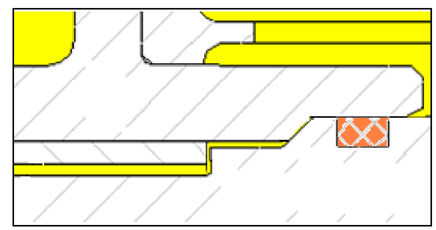
the amplitude-frequency characteristics of both cases of the intermediate support – the soft support and the stiff support.

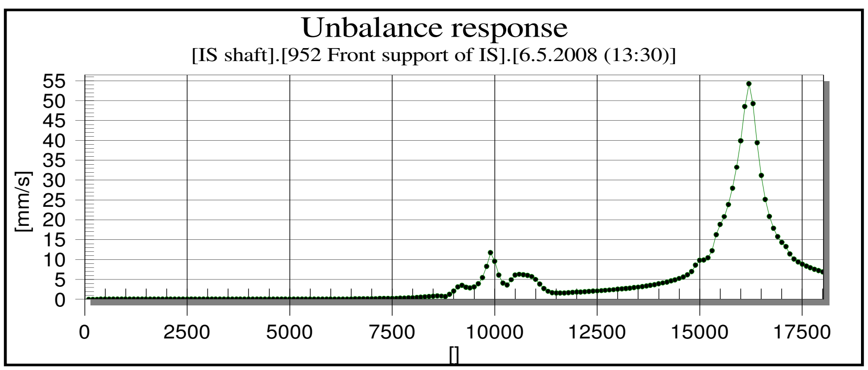
You can see that in the second case the resonance is excluded from the operating range

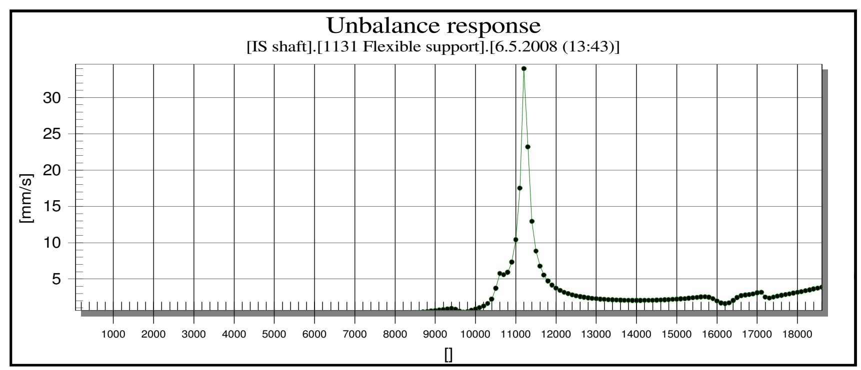
**Flexible support (clearance)**



**Stiff support (no clearance)**





# Test results (start-up and shut-down)

The experimental results obtained at the start up and shut down regimes, when testing compressor were carried out. About legend:

The blue line – rotor rotation speed, %

Red and green lines – vibration speed (measured form intermediate support accelerometers), mm/sec

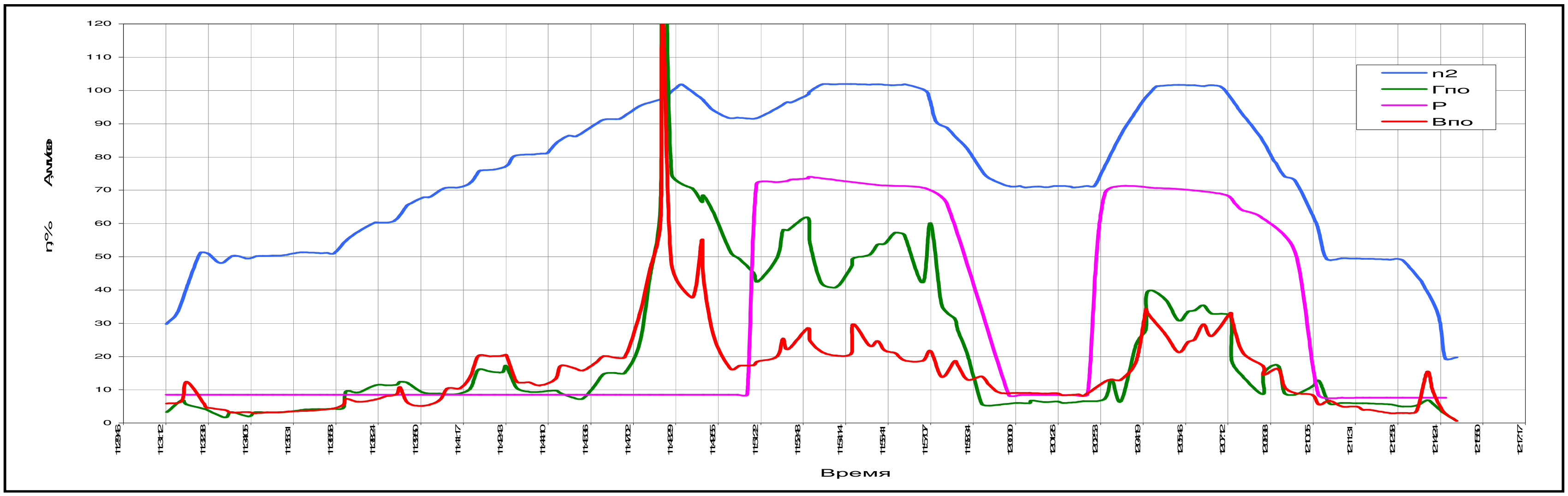
Pink colure line - air pressure in the control chamber (there is no pressure axis at this chart, only line)

The sharp resonance peak was met when increasing of rotation speed (97% ~16000 rpm). The vibration level was too large and we had no chance to transit the critical speed.

So, the rotation speed was decreased up to 92 % and then the air pressure was added to the control chamber (about 3 bars). The clearance was removed in the intermediate support. The support became a stiff one.

The following start-up of the rotor was carried out without large vibrations. The measurements of the compressor parameters were also carried out.

The obtained results showed the efficiency of the **support with controllable stiffness properties.** The design of the controllable support was patented




САТУРН
НАУЧНО-ПРОИЗВОДСТВЕННОЕ ОБЪЕДИНЕНИЕ

TRANZIT