

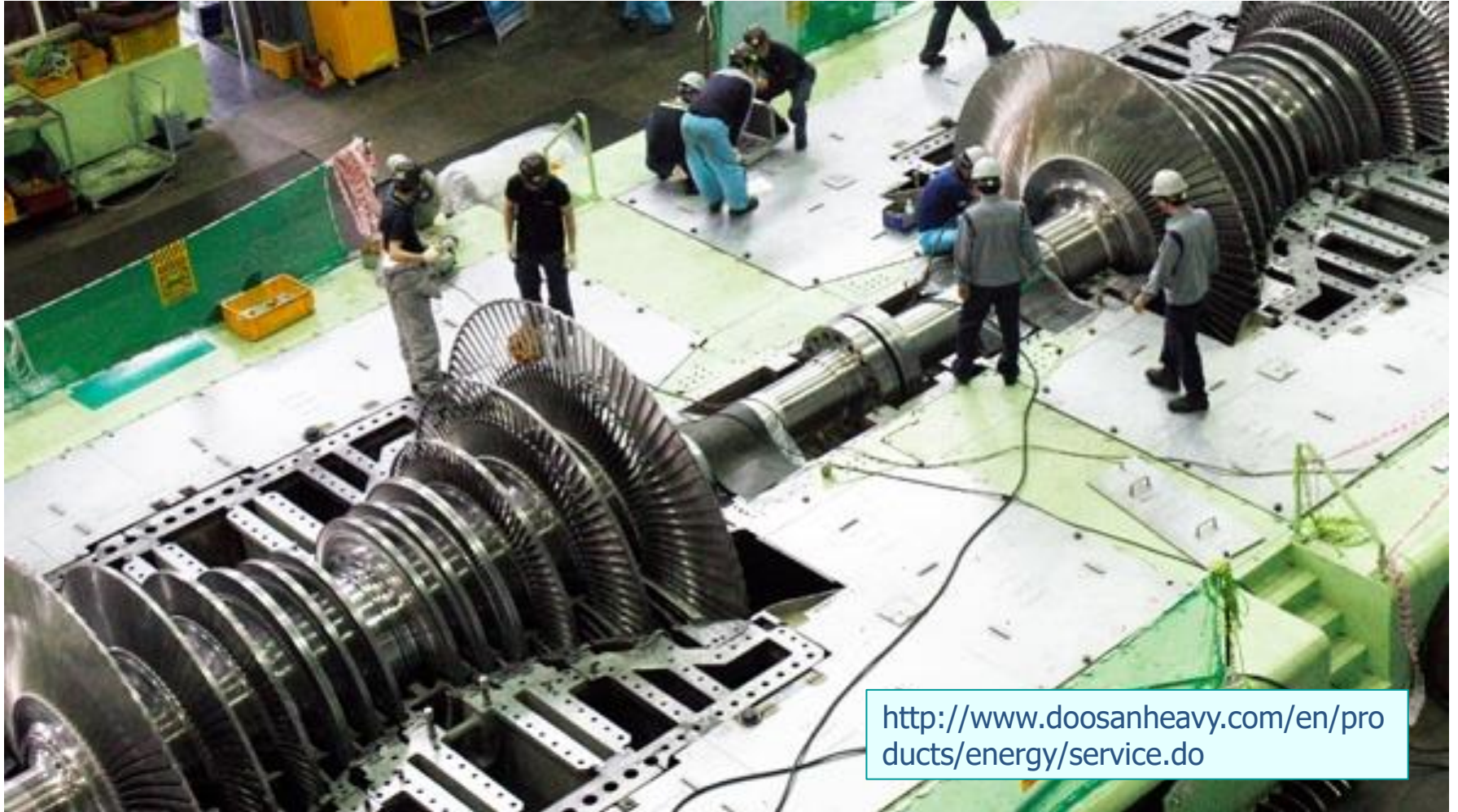


Clearances and Rubbings

DYNAMICS R4

Научно-технический центр "Альфа-Транзит"





<http://www.doosanheavy.com/en/products/energy/service.do>

Steam Turbines

- power unit turbine accident 225 Mw station "Gallatin" (United States), June 19, 1974;
- accident at a thermal power plant in the United States (Tennessee, 1974);
-
- accident in Russia - Kashirskaya Termal Power Plant of 300 Mw (October 2002);
-
- accident in Ukraine on one of the power units Pridneprovskaya TPP (2007);
-
- accident in Russia OAO ZSMK (2010).

Steam Turbines

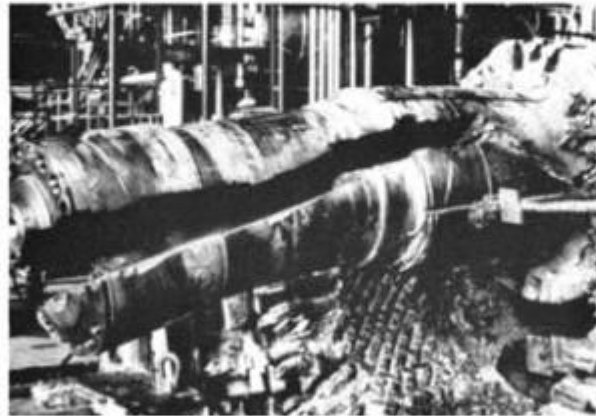
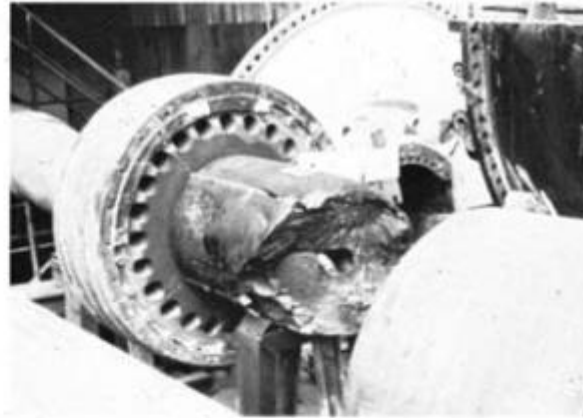
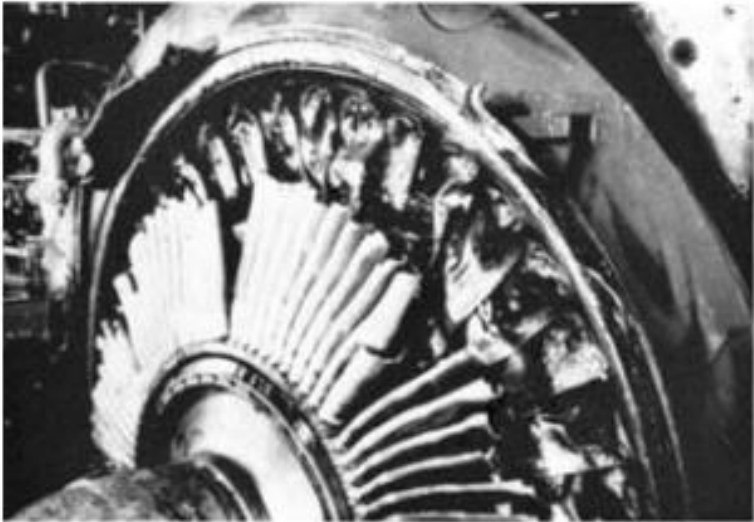
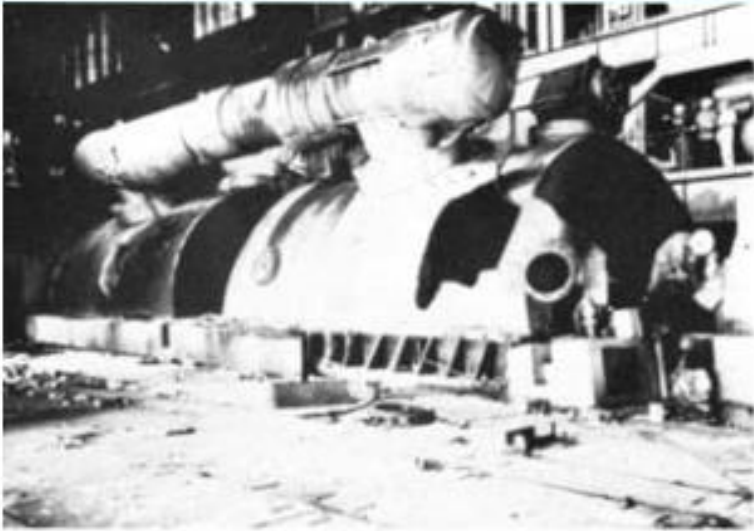
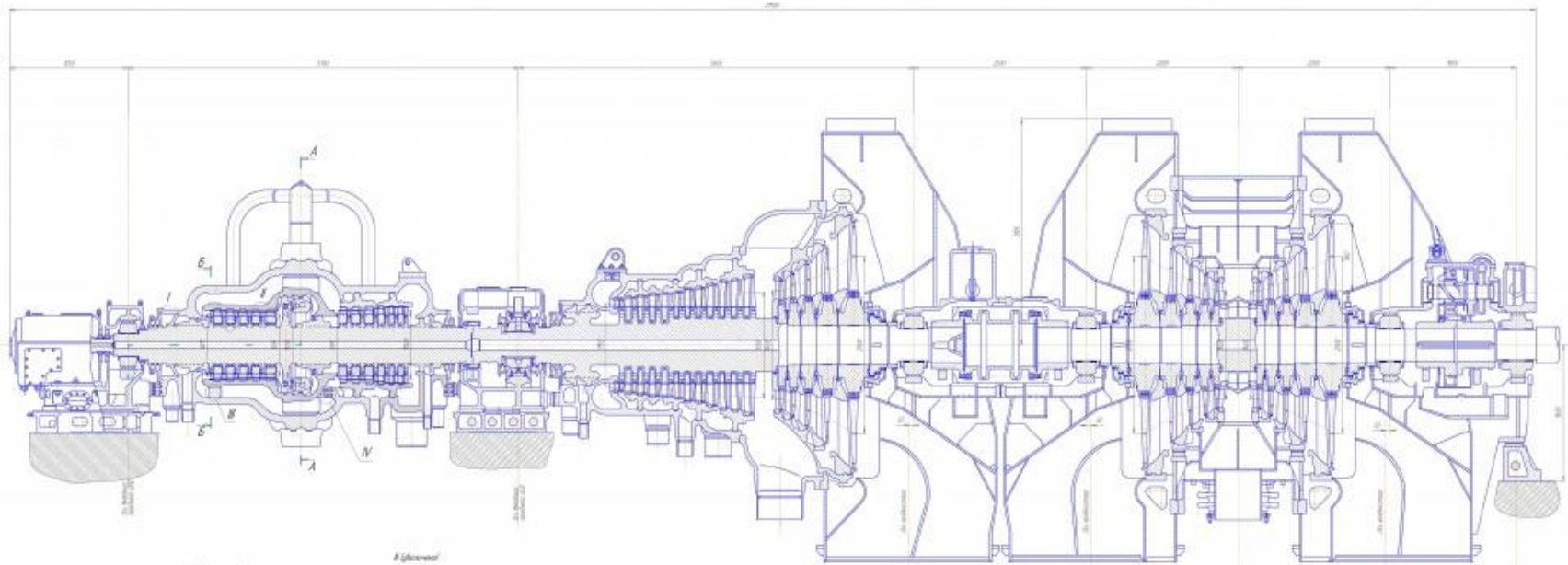


FIGURE 14 Photographs from two catastrophic failures in the 1970s of large 600 MW steam turbine-generator sets. Using nonlinear rotor dynamic response computations, failures could be potentially traced to the large unbalance from loss of one or more large low-pressure turbine blades at running speed, coupled with the behavior of fixed-arc journal bearings during large unbalance.

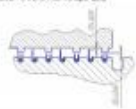
Steam Turbines disasters



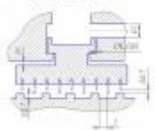
Case Study of Steam Turbine K-300-240-1



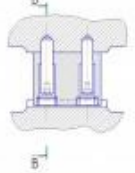
I (деталь) корпус подшипника
шпин в нижней части (1:2)



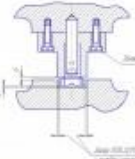
II (деталь) корпус подшипника
шпин в верхней части (1:2)



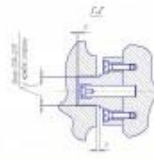
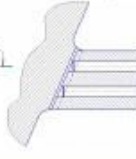
III (деталь) шпин



IV (деталь) корпус подшипника
шпин в нижней части (1:2)



V (деталь) корпус подшипника
шпин в верхней части (1:2)



| № | Исполнитель | Проверенный | Дата |
|----|-------------|-------------|------------|
| 1 | И.И.И. | И.И.И. | 01.01.2020 |
| 2 | И.И.И. | И.И.И. | 01.01.2020 |
| 3 | И.И.И. | И.И.И. | 01.01.2020 |
| 4 | И.И.И. | И.И.И. | 01.01.2020 |
| 5 | И.И.И. | И.И.И. | 01.01.2020 |
| 6 | И.И.И. | И.И.И. | 01.01.2020 |
| 7 | И.И.И. | И.И.И. | 01.01.2020 |
| 8 | И.И.И. | И.И.И. | 01.01.2020 |
| 9 | И.И.И. | И.И.И. | 01.01.2020 |
| 10 | И.И.И. | И.И.И. | 01.01.2020 |

Destruction of steam turbine K- 300 MW



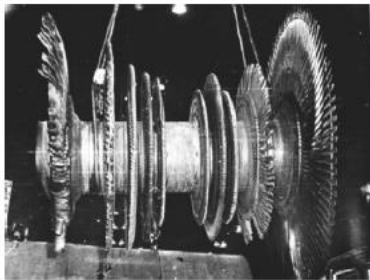
The accident happened on the complete destruction of the turbine and generator

Accident of Kashirskaya TPP – 2002

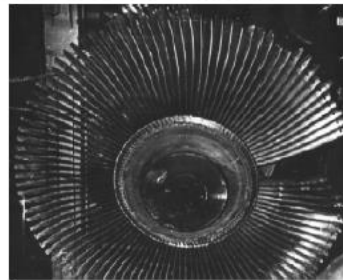
At the time of the accident the steam turbine had generation 228.5 thous. h. The appointed individual resource 250 thousand. h.

Number of accumulated launches-190. Turbine generator was put into operation in 1968, and during this period was repaired 14 times.

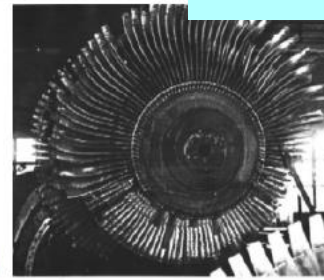
Steam parameters, vibration and other indicators were within normal limits.



a)



b)

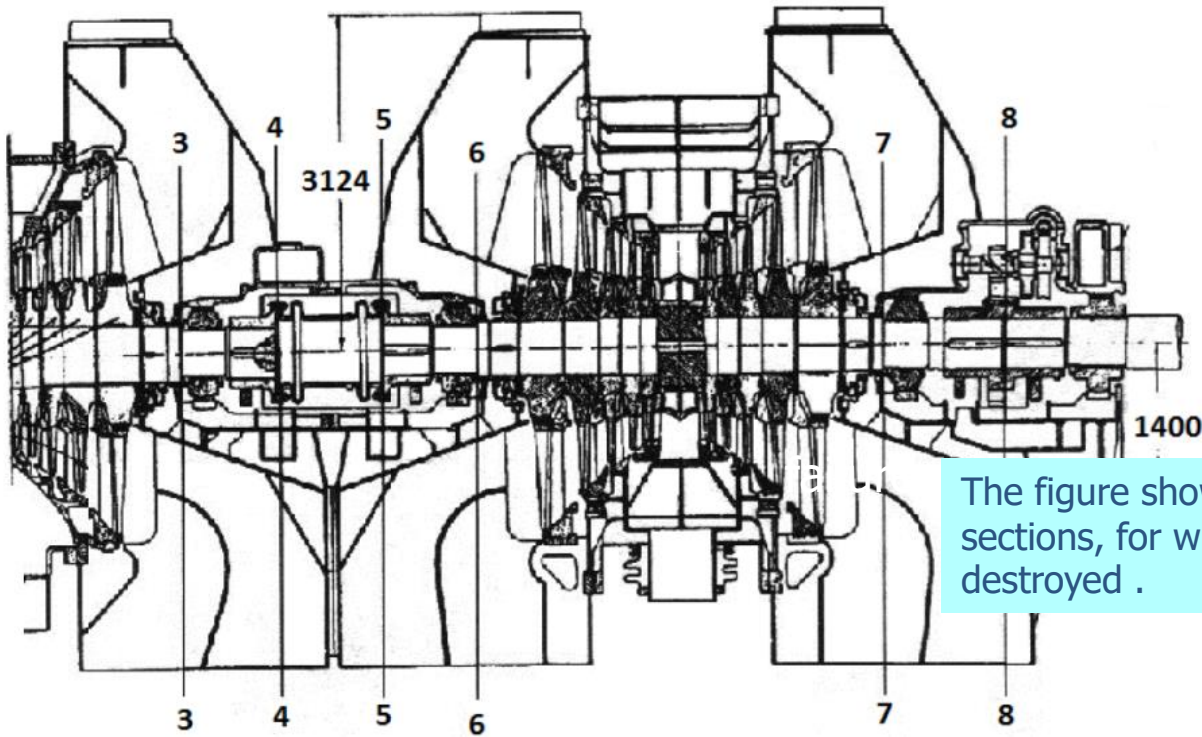


b)



z)

Destruction of steam turbine K- 300 MW



The figure shows the turbine and marked sections, for which the shafting was destroyed .

All the fracture turbine shafting have a power character twisting with or without proportion flexural component.

No indication of fatigue damage has been detected. This reflects an important dynamic twisting caused by rotor braking speed with large negative acceleration.

Bending component is probably the consequence of large shaft precession with big deflection

Destruction of steam turbine and generator



Destruction of generator shaft



Heavy damages of blades and disks

The reasons of heavy destructions enumerating



- Breakage blades or group of blades, leading to large imbalances and contact the shaft with the stator
- Small gaps between the crowns of impellers and stators, resulting in contacts of shaft and stator
- Bending and torsion vibrations, equal to the working mode of the turbine, imbalances in the work process
- Contact the turbo generator rotor windings on the stator
- Short circuit in turbo generator
- Violation of stiffness characteristics of the shafts train leading to a shift of resonance modes
- Incorrect design
- Drop the rotor supported AMB on safety bearings
- Shafting cracks due to low cycle fatigue, resulting in contacts of shaft and stator, etc

These terms and conditions do not always lead to such serious consequences, even for the same type of turbines.

This means that the design of turbines should take account of the possible consequences of any irregularities in the work of turbine unit

Destruction of steam turbine K- 300 MW

But despite their reason difference, destruction of most of them has the same process:

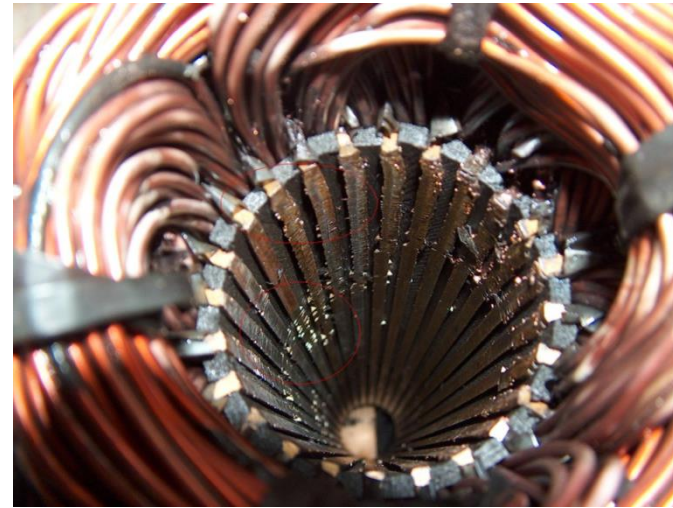
- Contact shafts and housings of gas turbines shafts train
 - Sharp braking individual sections of shafts train up full stop with liberation of vast quantities of energy at the time of braking
 - Twisting of shafts train sections relative to each other and finally, the complete destruction of the turbines and perhaps the whole energy complex - turbine halls and buildings
-

Destruction of rotating machines

Let us explain the damage and destruction mechanism of rotating machinery on submersible motor example



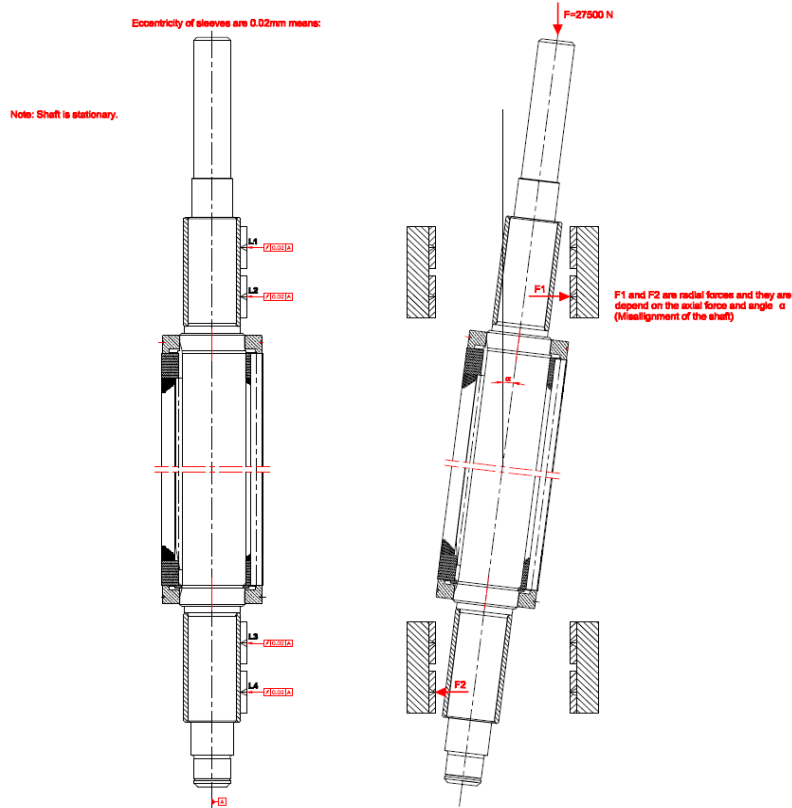
Destruction of Submersible Motor



Destruction of motor journal bearings shaft



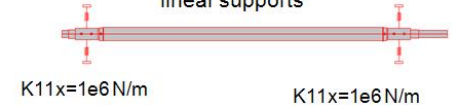
Submersible Motor Wrong Design



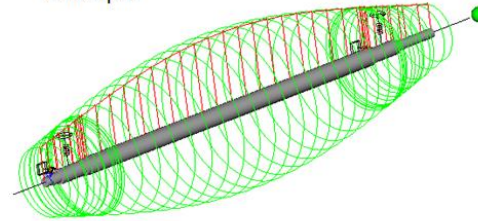
Critical speeds

| |
|---------------|
| 2854.8 (47.6) |
| 2855.6 (47.6) |
| 5269.0 (87.8) |
| 5279.4 (88.0) |

Al6p shaft model with linear supports



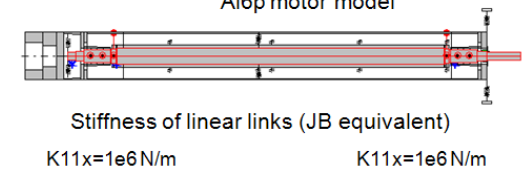
Forward precession
2855 rpm



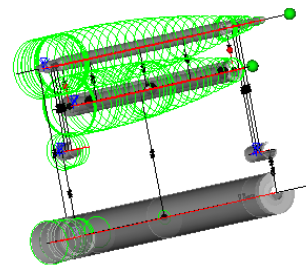
Critical speeds

| |
|---------------|
| 1413.0 (23.5) |
| 1414.0 (23.6) |
| 2381.0 (39.7) |
| 2386.0 (39.8) |

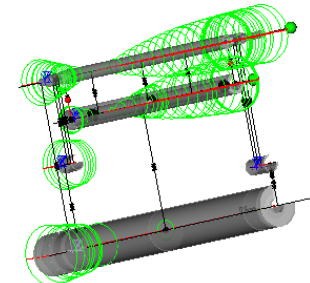
Al6p motor model



1414 rpm



2386 rpm



Destruction of Submersible Motor

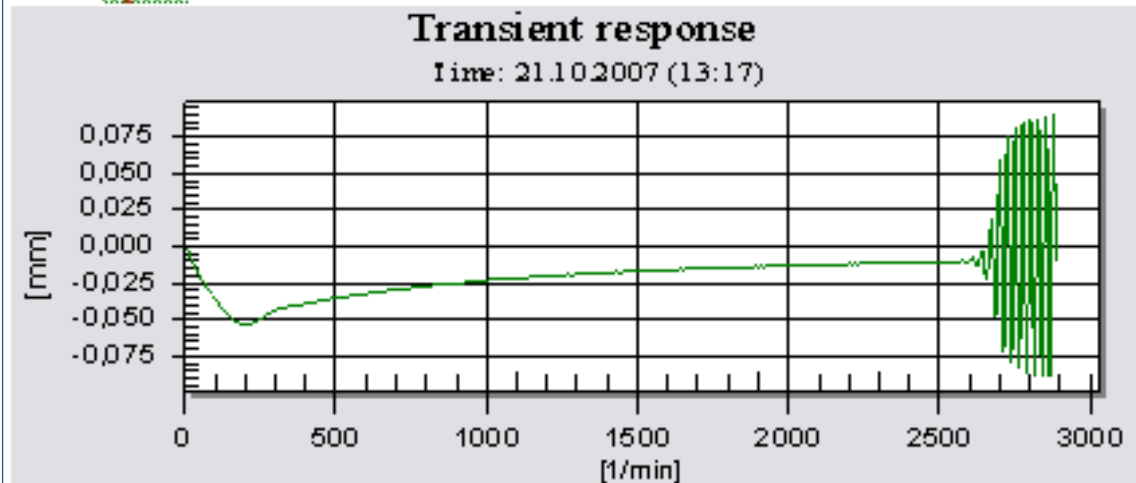
Additional static moment on the shaft due axial force 10 Nm

Time 0-0.4 - no moment

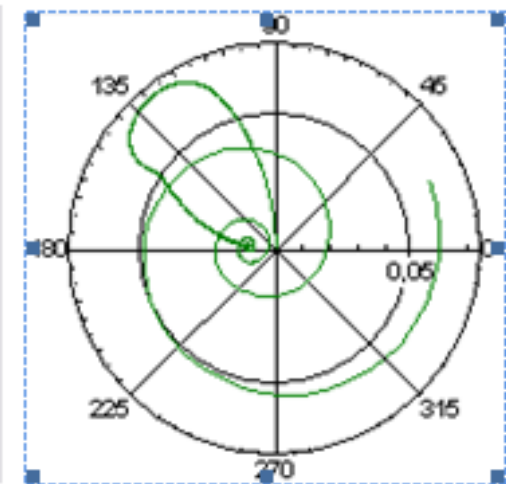
Time 0.4..... - applied moment

1st left bearing

Start up 0... 6000



Instability ~ 2500 rpm

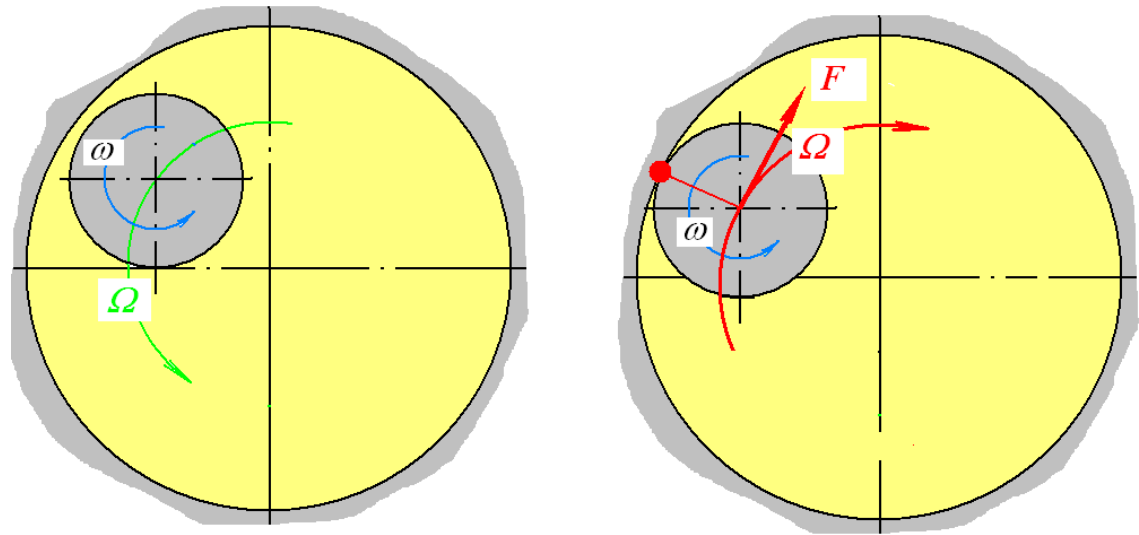


Loss of stability due incorrect choose of rotor structure and journal bearings/Operating speed 3000 rpm

1. Critical speed in the work range
2. Clearance adjustment
3. Rough rubbing
4. Shaft braking

Fast rotor moving to zero speed and appearance of backward precession

Forward precession of rotor – normal work



The reason of destruction is wrong design

DYNAMICS R4 – powerful tools for design and dynamic improvement of rotating machinery

[- Движение в зазоре.rdm:1]

File Edit View Tools Window Help

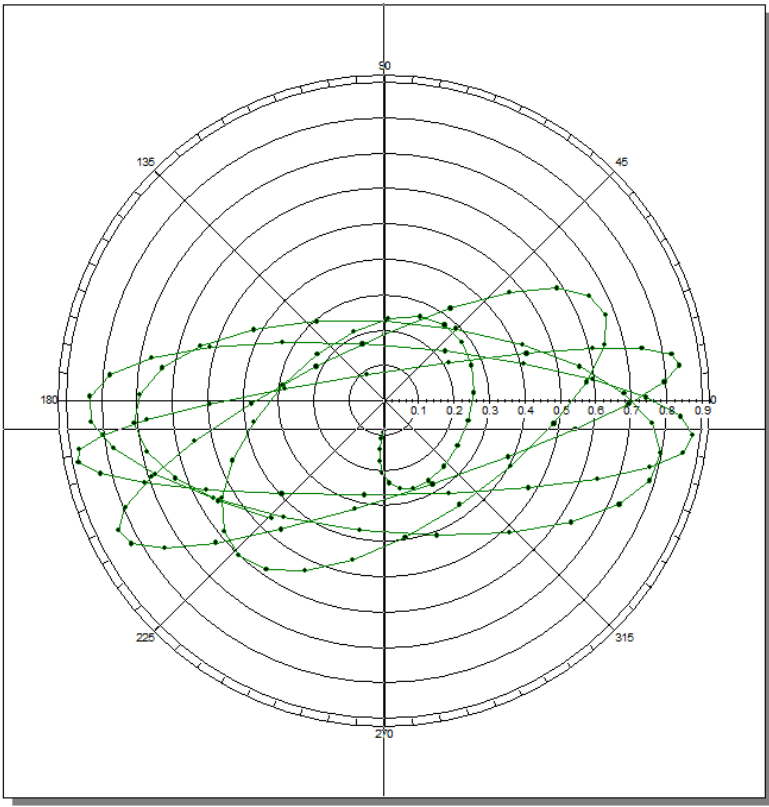
Freeze Start Break 2D Sort by absolute time Subsystem 1 0 0 0 Abstract element 2

Example 9 Y Displacement

Subsystem 1 -90.011; 0.082

Orbit (Transient response)

[Subsystem 1].[0 0 0 Abstract element 2].[30.10.2016 (14:42)]



0 0 0 Abstract element 2
0 0 1 Link 1
0 0 1 Mass 2
0 0 1 Abstract element 2 5
0 0 2 Closing section
omega_z
r_z

Des Designation
t_st_real 0 s Real start time
t_interval 0.12 s Time interval

Time of integrating

Log

```
Calculation of transient response
D:\STATM 2016\NEW SITE\Движение в заз:
begin of SOE integrator initializing
enter calculateSystemMassMatrix
/exit calculateSystemMassMatrix tim
/enter calculateSystemComplianceMat:
Zero roots amount: 0 stations = .
SystemComplianceMatrix time: 0.000!
/end of SOE integrator initializing,
enter calculateEigenvalues
24/24
/mem alloc in calculateEigenvalues time
System matrix M is not positive de:
24/3
/prepare tmem alloc in calculateEigenv:
enter calculateSymmGeneralizedEig:
calculateSymmGeneralizedEigenvalues tim
0 0.096493
1 2864.788976
2 3307.973373
/exit calculateEigenvalues time: 0.0!
Eigenvectors time: 8.8e-005 sec
enter Basis calculateEnergy
calculateEnergy time: 7.2e-005 sec
modeshapes processing time: 0.00022 !
calculateEigenvectors time: 0.00045 !
-0.999900 0
-0.975800 0
-0.951700 0
-0.927600 0
-0.903500 0
-0.879400 0
-0.855300 0
-0.831200 0
-0.807100 0
-0.783000 1
-0.758900 0
-0.734800 0
-0.710700 0
-0.686600 0
-0.662500 0
-0.638400 0
-0.614300 0
-0.590200 0
-0.566100 0
-0.542000 0
-0.517900 0
-0.493800 0
-0.469700 0
-0.445600 0
-0.421500 0
-0.397400 0
```

Elements Log Str_History

CAP NUM SCRL

For Help, press F1

No rubbings? Instability...

[-] (Движение в зоре.rdm:1)

File Edit View Tools Window Help

Example 9

- Subsystem 1
 - Abstract element 2
 - Mass 2
 - Обрыв лопатки 5
 - Abstract element 2 5
 - Input speed 1
 - Link 1
 - Variables
 - Subsystem 1_Input speed 1
 - Materials
 - Algorithms
 - Basis
 - Transient response
 - Mean value
 - Fast Fourier Transform
 - Waterfall diagram
 - Orbit (Transient response)

Freeze

Subsystem 1 Example 9

Example 9.Link 1
Example 9
GCx=0m, GCy=0m, GCz=0.001m, sizeZ=0.002m
m=10000kg, Jx=0kg m2, Jy=0kg m2, Jz=0kg m2

Log

```
D:\CTAT&H 2016\NEW SITE\...
begin of SOE integrator initializing
enter calculateSystemMassMatrix
/exit calculateSystemMassMatrix
enter calculateSystemComplianceMatr
Zero roots amount: 0 stations =
SystemComplianceMatrix time: 0.0001
/end of SOE integrator initializing,
enter calculateEigenvalues
24/24
/ mem alloc in calculateEigenvalues time
System matrix M is not positive de...
```

Matrix

Stiffness

| | | ut_x | ut_y | ut_z | ur_x | ur_y | ur_z |
|----|-----|--------|----------|------|------|------|------|
| | | m | m | m | rad | rad | rad |
| Fx | N | 9e+008 | 0 | 0 | 0 | 0 | 0 |
| Fy | N | | 1.2e+009 | 0 | 0 | 0 | 0 |
| Fz | N | | | 1 | 0 | 0 | 0 |
| Mx | N m | | | | 1 | 0 | 0 |
| My | N m | | | | | 1 | 0 |
| Mz | N m | | | | | | 1 |

Damping

| | | vt_x | vt_y | vt_z | vr_x | vr_y | vr_z |
|----|-------|--------|--------|------|-------|-------|-------|
| | | m... | m... | m/s | rad/s | rad/s | rad/s |
| Fx | N | 200000 | | | | | |
| Fy | N | | 300000 | | | | |
| Fz | N | | | 0 | | | |
| Mx | N ... | | | | 0 | | |
| My | N ... | | | | | 0 | |
| Mz | N ... | | | | | | 0 |

Des Link 1

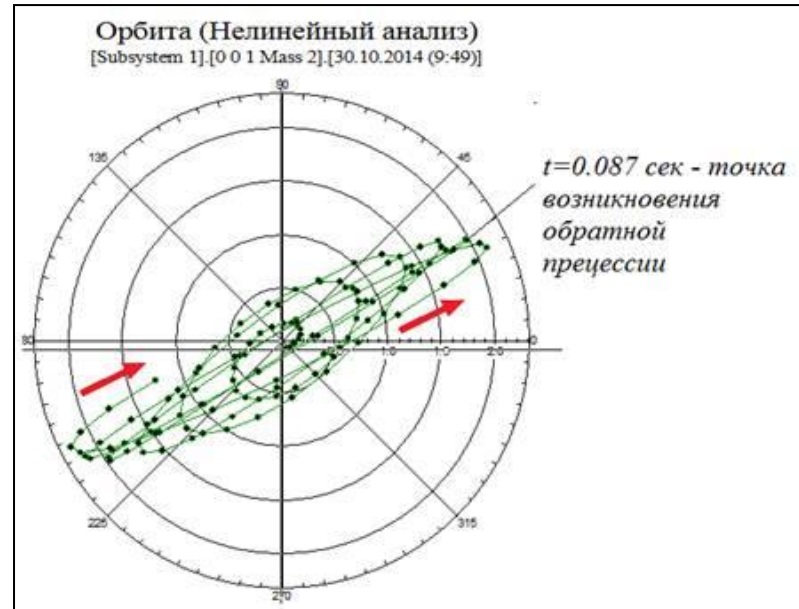
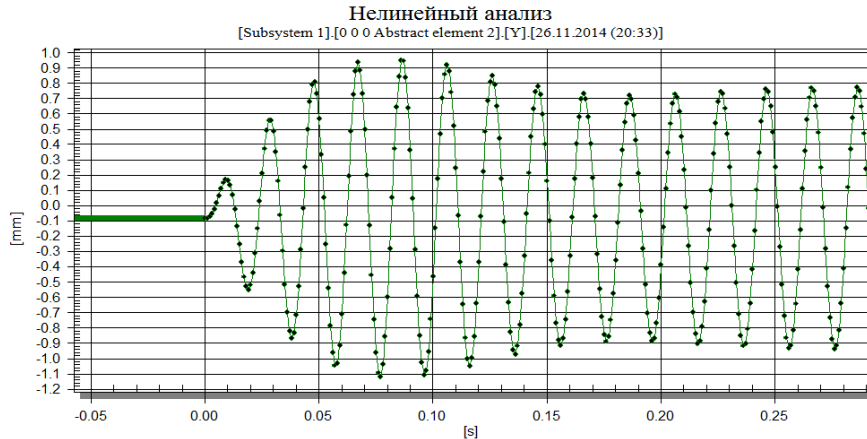
| | |
|--------------|-----------------------|
| conn_type | via body |
| side1_subs | Subsystem 1.Example 9 |
| side1_l | 1 mm |
| side2_subs | |
| trns_exclude | No |
| Type | Full |
| stiff_matrix | ... |
| damp_matrix | ... |
| d* | 0 mm |

For Help, press F1

Elements Log Str_History

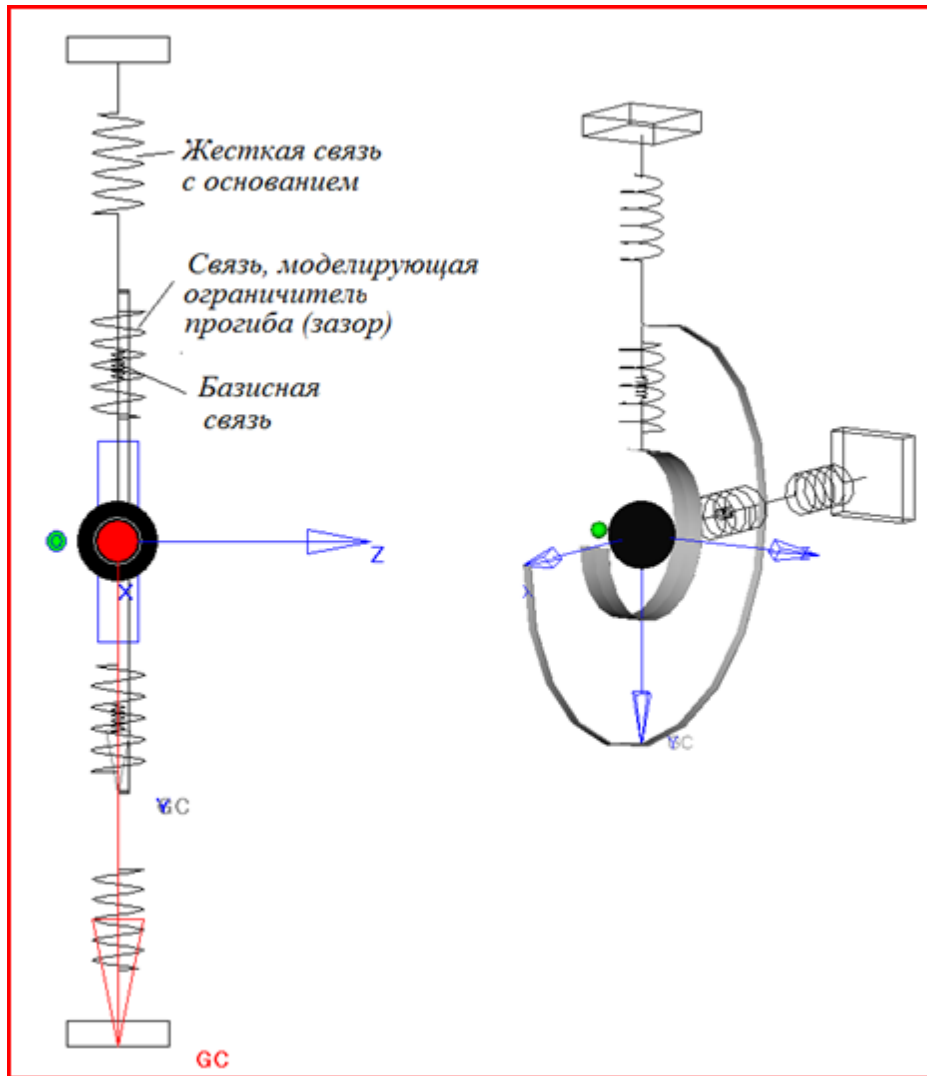
CAP NUM SCRL

No rubbings? Instability...



The point rotor with an orthotropic support was taken as an example how to simulate the rotor's motion in clearance without contact. Dependence of the rotor's motion on the position of the rotor's rotating speed ω at the unbalancing moment in relation to the natural frequencies p_1 and p_2 is shown.

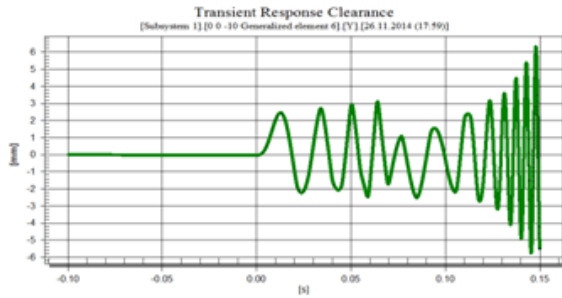
Going to backward precession takes place if rotating speed ω , which sudden unbalance happens at, is between the first natural frequency p_1 and the second one p_2 .



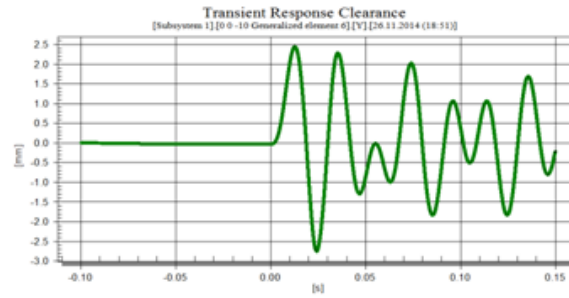
The point rotor having two freedom degrees was taken as an example to simulate the rotor's motion in clearance.

It is investigated how flexibility in the contact point influences precession type. It is shown that increase in flexibility in the contact point of the rotor and the stator decreases probability of the rotor's going to backward precession.

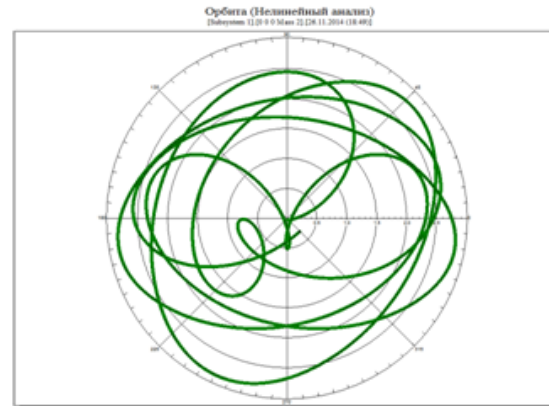
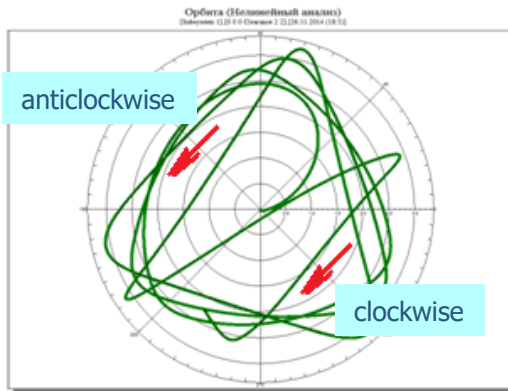
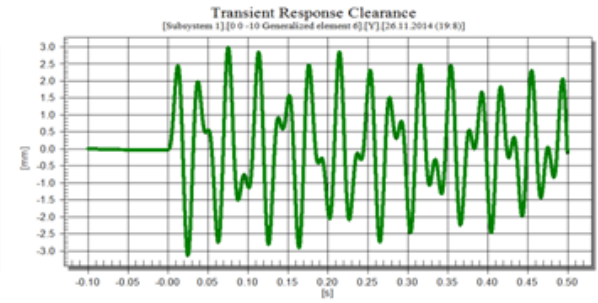
$$K_1=K_2=1e11 \text{ H/M}$$



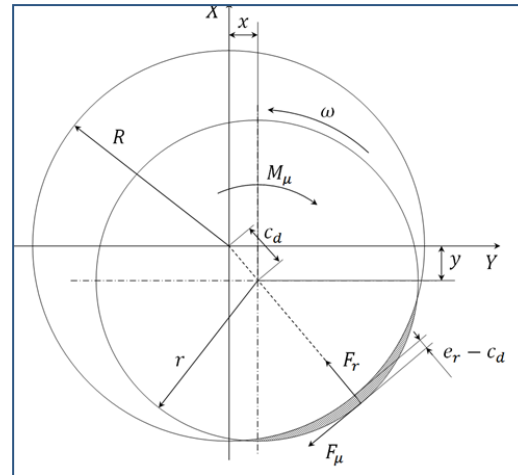
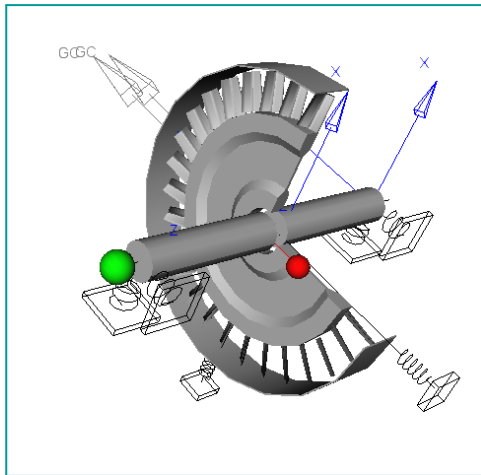
$$K_1=K_2=1e10 \text{ H/M}$$



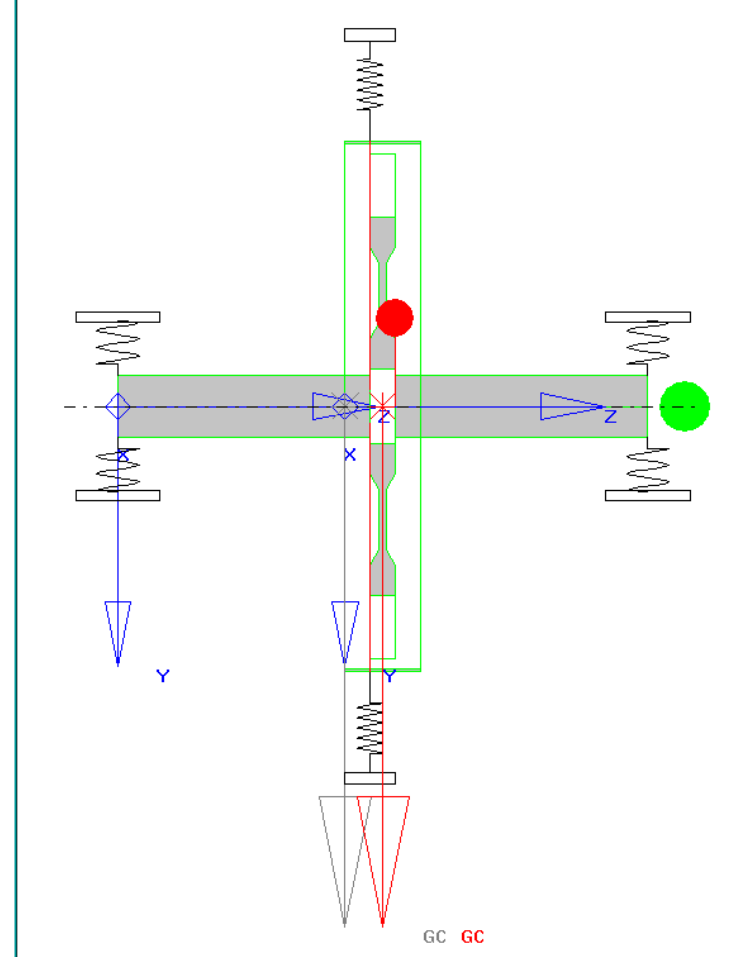
$$K_1=K_2=1e09 \text{ H/M}$$



Rubbing. [Dry bush]



Example 38.Clearance 3
 Example 38
 GCx=0m, GCy=0m, GCz=0.21m, sizeZ=0.06m
 m=7.16538kg, Jx=0.0961156kg m2, Jy=0.0961156kg m2, Jz=0.00192668kg m2



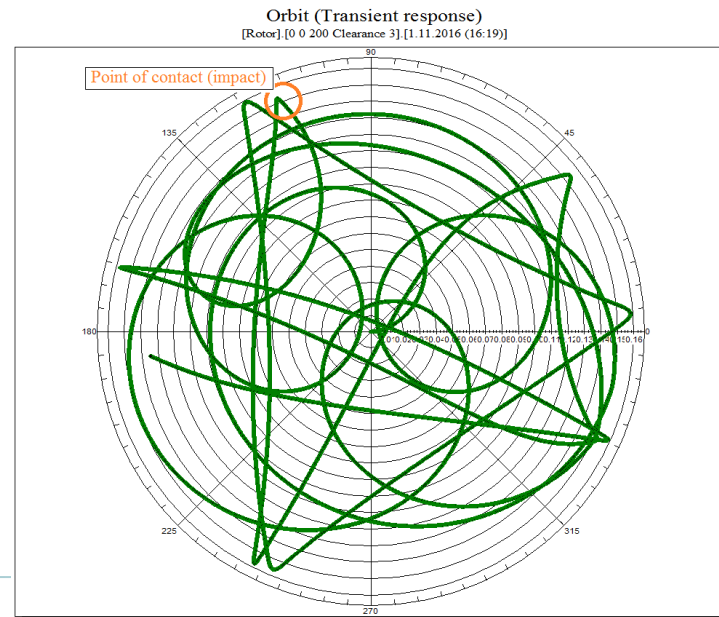
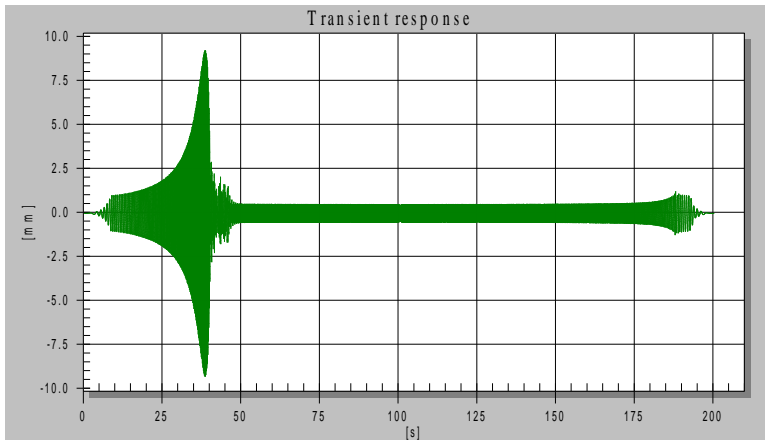
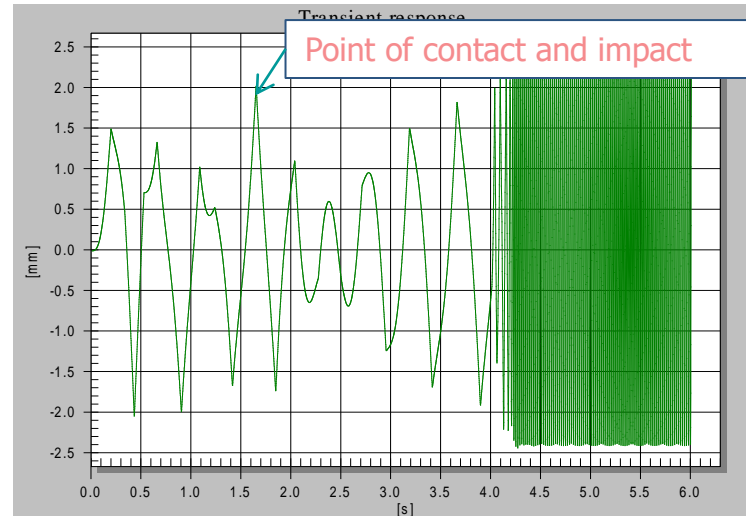
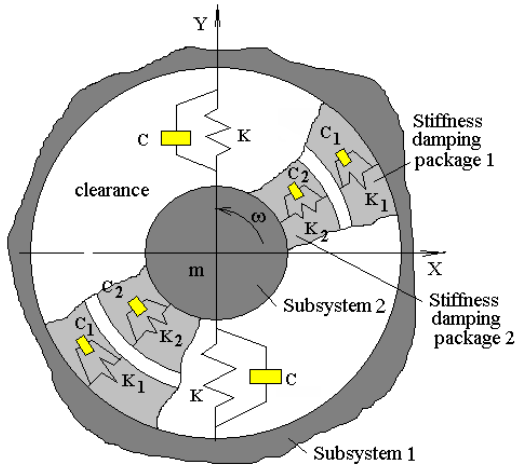
$$F_{\mu} = \begin{cases} \mu * F_r, \text{при } V > 0 \\ -\mu * F_r, \text{при } V < 0 \\ \mu_s * F_r, \text{при } V \leq V_{smin} \end{cases}$$

$$M_{\mu} = R * F_{\mu}$$

$$V_s = \Omega * \delta + (\omega_1 * r - \omega_2 * R)$$

$$|V_s| \leq V_{smin}$$

Rubbing . [Clearance]



Short circuit simulation [Torque load]

The [Torque load] element represents an external dynamic load applied to the shaft station. It is used for simulation of the dynamical variations of the torque load. For example, harmonic excitations can appear as a result of 2-phase, 3-phase short circuit in the electrical machines. Torque load is defined as a harmonic series. In order to simulate various behavior of dynamic torsion moment, a user can assign amplitude values for torque components, time constants and phases.

The following harmonic series is used to define the mathematical model of torque moment variations.

$$T = \begin{cases} T_{rated} [T_0 e^{-a_0 t} + T_1 e^{-a_1 t} \sin(\omega t + \varphi_1) + T_2 e^{-a_2 t} \sin(2\omega t + \varphi_2)], & t > t_1 \\ T_{rated}, & t \leq t_1 \end{cases}$$

where T_{rated} , T_0 , T_1 , T_2 , - the engine torque moment and coefficients for amplitude components of torque load variations., a_0 , a_1 , a_2 - time constants for decay process definition, φ_1 , φ_2 - phase angles, ω - grid frequency.

| Des | Torque Load | | Designation |
|------------|-------------|-------|--|
| z1 | 0 | mm | Start coordinate |
| R* | 0 | mm | Fictive radius |
| t_st_type | real | | Start time definition |
| t_st_real | 0.1 | s | Real start time |
| Trated | 31831 | N m | Steady state driving torque |
| T0 | 0.837 | | Aperiodic torque component |
| T1 | 9.234 | | First order harmonic torque component |
| T2 | 0.435 | | Second order harmonic torque component |
| a0 | 14.7 | | Time constant of aperiodic torque component |
| a1 | 13.8 | | Time constant of first order harmonic torque component |
| a2 | 13.8 | | Time constant of first order harmonic torque component |
| f | 3600 | 1/min | Grid frequency |
| phase1 | 0 | deg | Phase angle 1st harmonic torque component |
| phase2 | 0 | deg | Phase angle 2nd harmonic torque component |
| Visibility | 0 | | Element Visibility |

Transient response

[Subsystem 1].[0 0 400 Closing section].[Z].[5.2.2013 (16:44)]

