Expo Engine 2010

Crankshaft Analysis

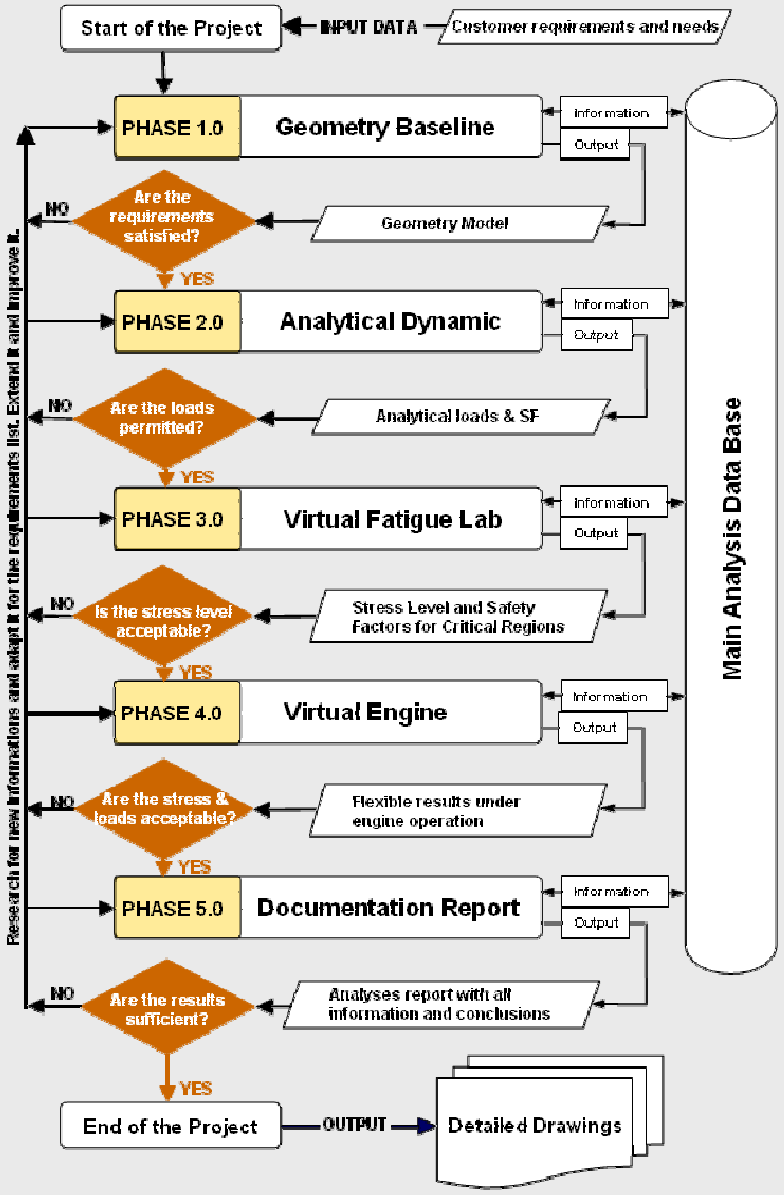
June 22, 2010

Alex de Souza Rodrigues
Development Engineering
ThyssenKrupp Metalúrgica Campo Limpo - Brazil
E-mail: alex.rodrigues@thyssenkrupp.com
Phone: +55 11 4039-9135 Mobile: +55 11 6772-7762

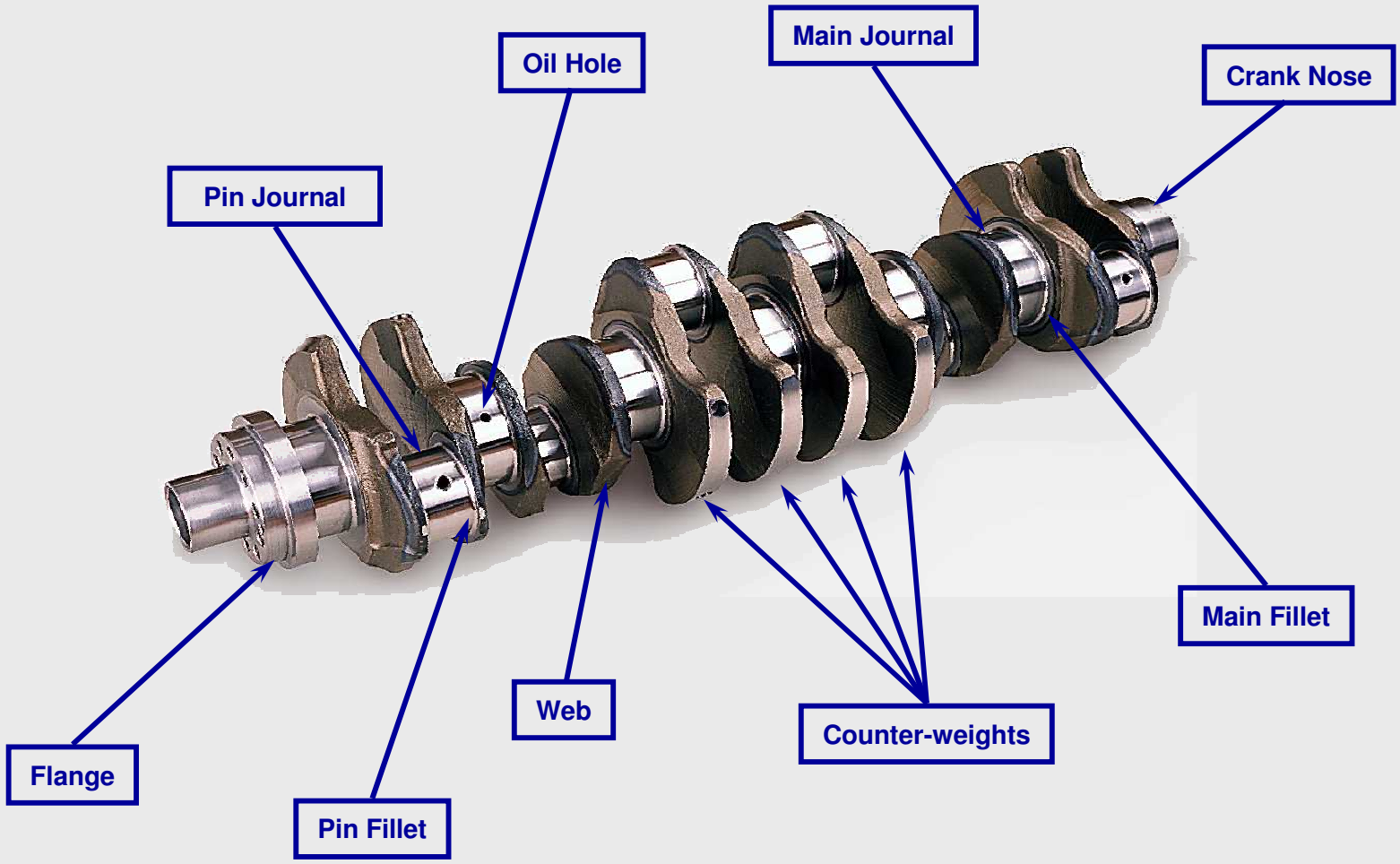
Agenda

1. Crankshaft Development
2. Technical Nomenclature
3. Bench Test
4. Dynamic Analysis
5. Flexible Dynamic Analysis
6. Conclusion
7. Final

1. Crankshaft Development

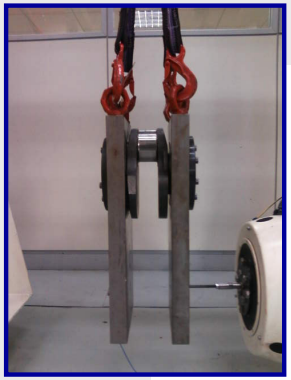


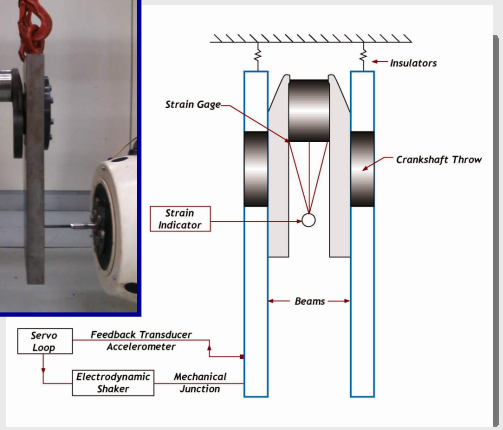
2. Technical Nomenclature



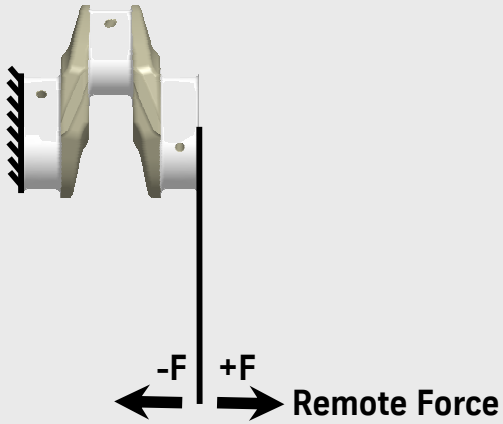
3. Bench Test

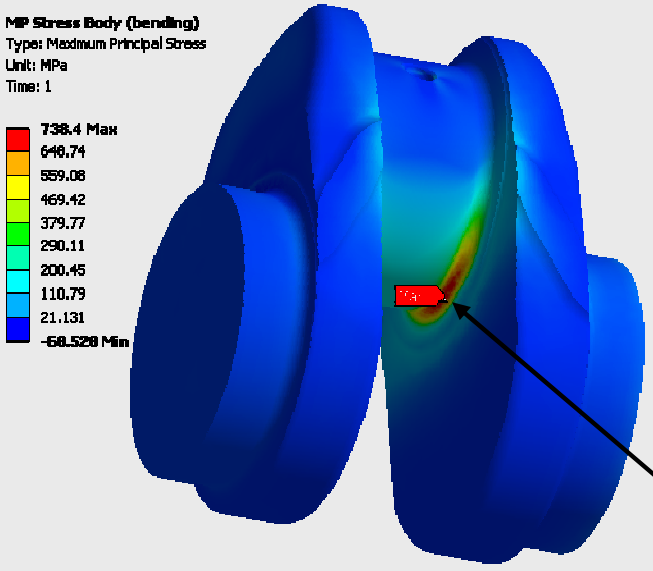
Bench Bending Test

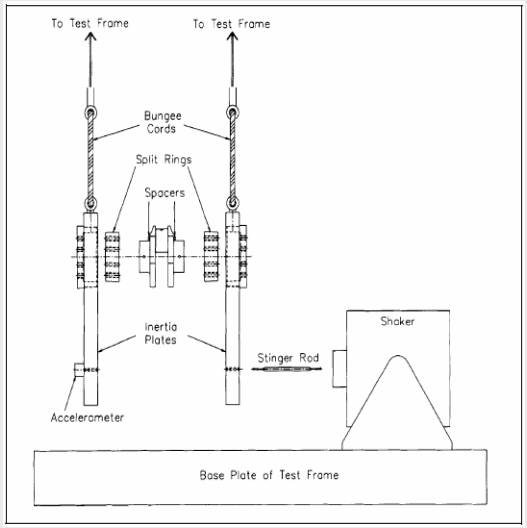




Virtual Bending Test







Strain gauge

Material Properties identification based on experimental tests with crankshafts under bending load

- Stair Case Method is applied for endurance limit evaluation
- 10 million cycles
- The stresses are measured directly in the bearings fillets by strain gauges (positions 1, 2, 3 and 4)
- Endurance limit is calculated for bearings fillets based on measured data and statistical treatment

Material Properties

- SR: ultimate tensile strength
- SE: yield tensile strength
- E: Young's modulus
- Poisson
- NC and NL: number of load cycles
- SC and SL: endurance limits

SN Methodology

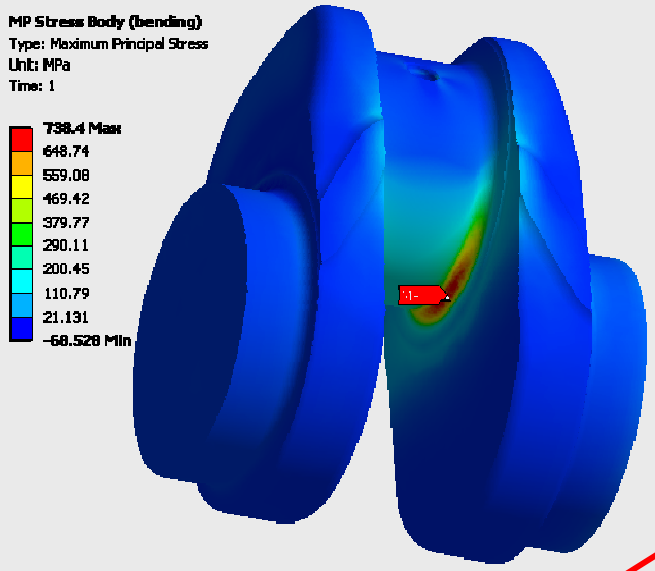
- PUC Criteria

3. Bench Test

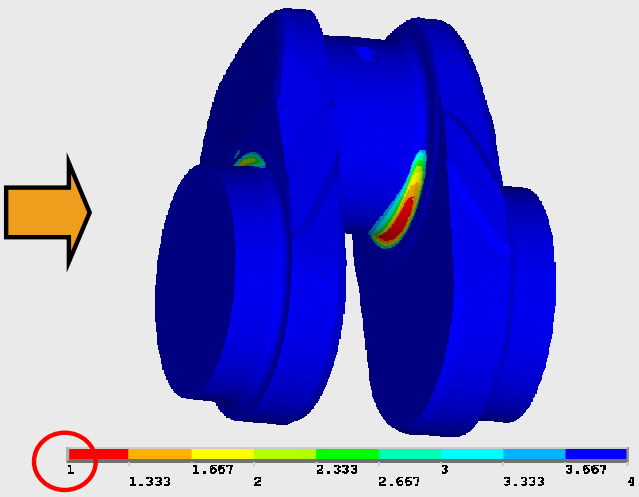
Stair Case Method for Bending

Table 1: Data Sheet

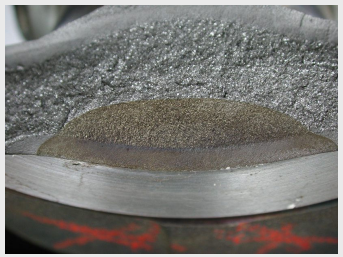
SAMPLE ID #	PIN #	Stress in the Pin Fillet (ksi)	# of cycles	Failure Location
1:3	3	120,0	1.595.264	4
1:5	5	115,0	870.672	3
2:4	4	110,0	1.077.320	2
2:6	6	105,0	10.000.000	-
3:1	1	110,0	10.000.000	-
3:3	3	115,0	6.450.144	4
4:2	2	110,0	10.000.000	-
4:4	4	115,0	2.656.608	4
5:1	1	110,0	10.000.000	-
5:3	3	115,0	10.000.000	-

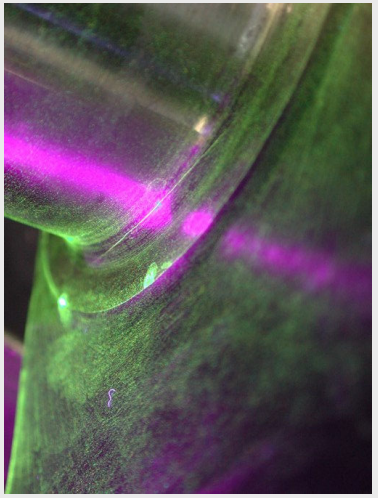


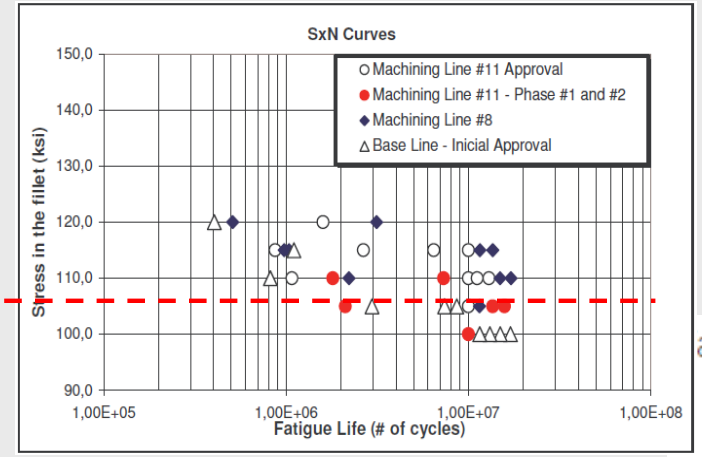
Fatigue Safety Factor



Minimum SF=1 for infinite life







107.1

Endurance Limit (SC) for 1 million cycles (NC)

able 2: Bending fatigue Results

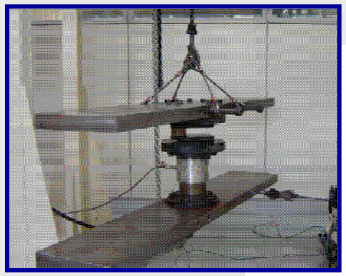
Results	
50% (mean)	112,5 ksi
95%	107,1 ksi
Std Deviation	3,5 ksi

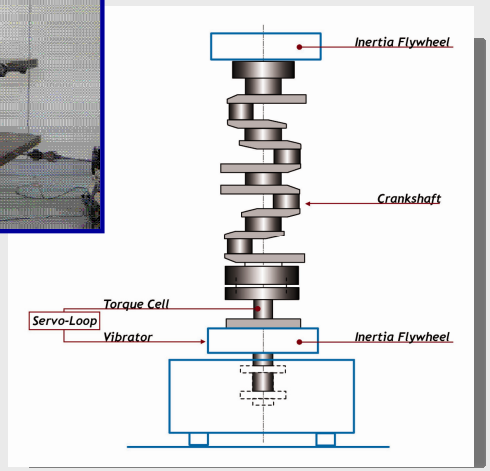
738 MPa

Endurance Limit (SL) for 10 million cycles (NL)

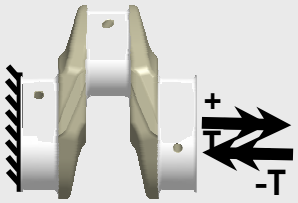
3. Bench Test

Bench Torsion Test

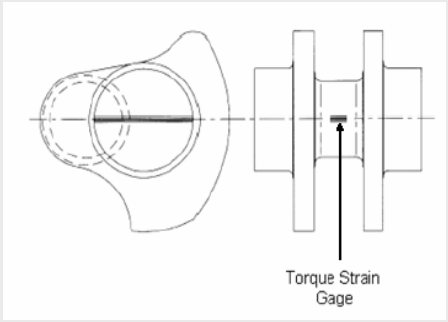


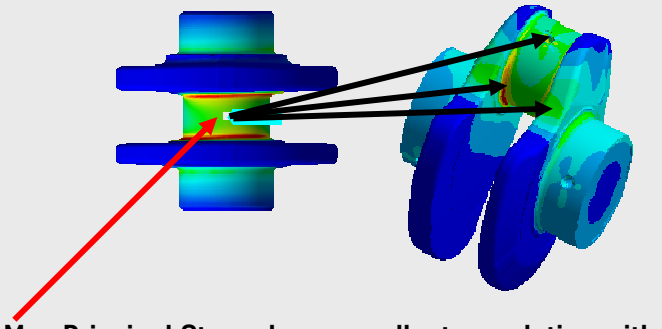


Virtual Torsion Test



Torsional Strain Gauge Position





Max Principal Stress have excellent correlation with strain gauge measurement

Material Properties identification based on experimental tests with crankshafts under torsion load

- Stair Case Method is applied for endurance limit evaluation
- 10 million cycles
- The stresses are measured in the bearings center by torque strain gauges
- Endurance limits are calculated for bearings fillets, webs and oil hole regions based on measured data and FEA results extrapolation
- The number of specimen tested in torsional stair cases is not enough to allow statistical treatment. Thus, the endurance limit is obtained from critical specimen result

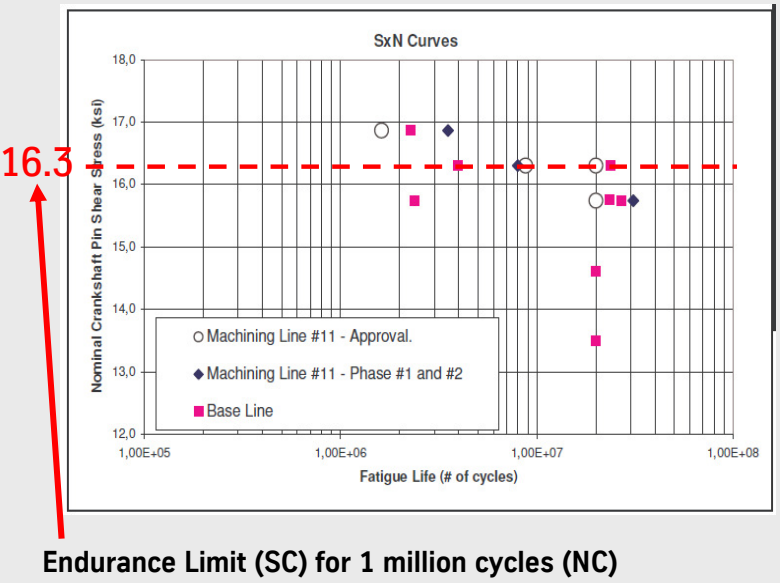
Material Properties

- SR: ultimate tensile strength
- SE: yield tensile strength
- E: Young's modulus
- Poisson
- NC and NL: number of load cycles
- SC and SL: endurance limits

SN Methodology

- PUC Criteria

3. Bench Test

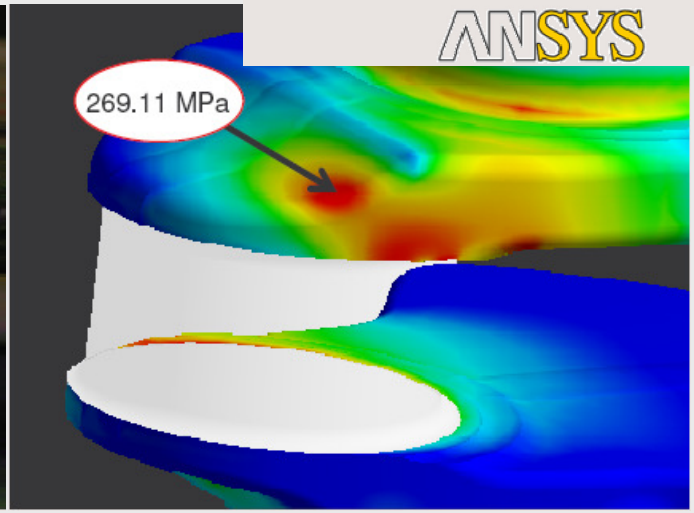


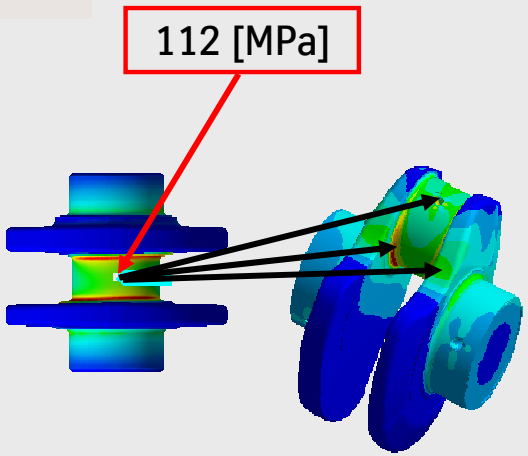
Endurance Limit (SC) for 1 million cycles (NC)

Stair Case Method for Torsion

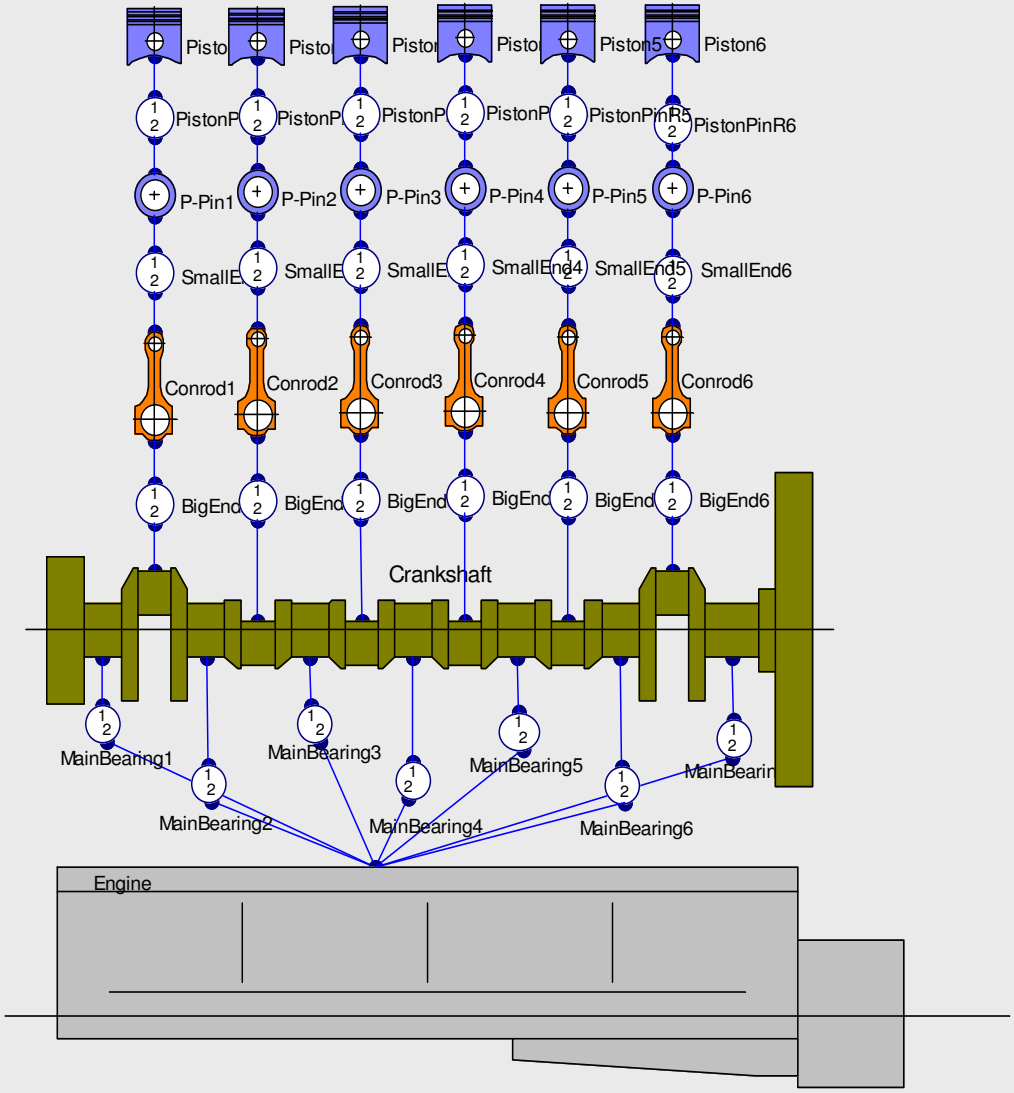
Endurance Limit (SL) for 10 million cycles (NL) @ strain gage

PIN Journals #	Torsional Moment (KNm)	Nominal Crankshaft Pin Shear Stress		# of cycles	Failure Location
		ksi	MPa		
1:1	7,50	16,9	116,3	1.616.000	Oil hole
2:2	7,25	16,3	112,4	8.782.544	Oil hole
3:5	7,00	15,7	108,5	20.000.000	-
4:6	7,25	16,3	112,4	20.000.000	-

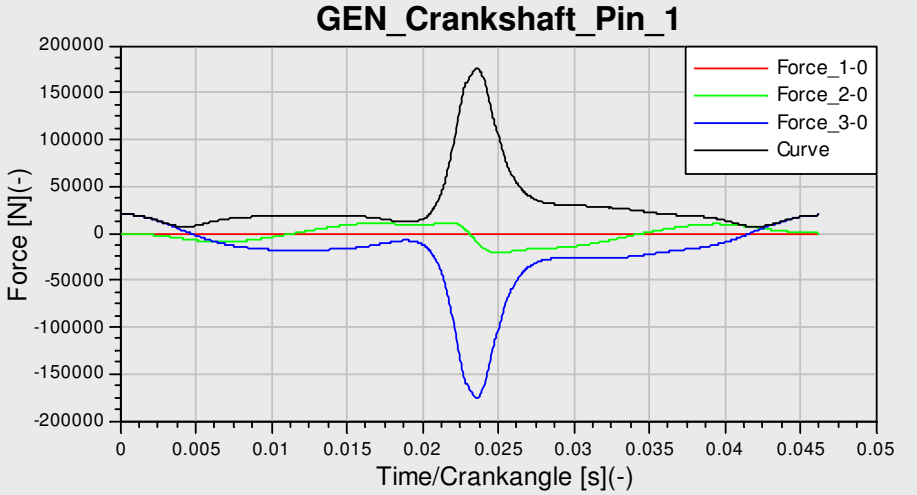




4. Dynamic System

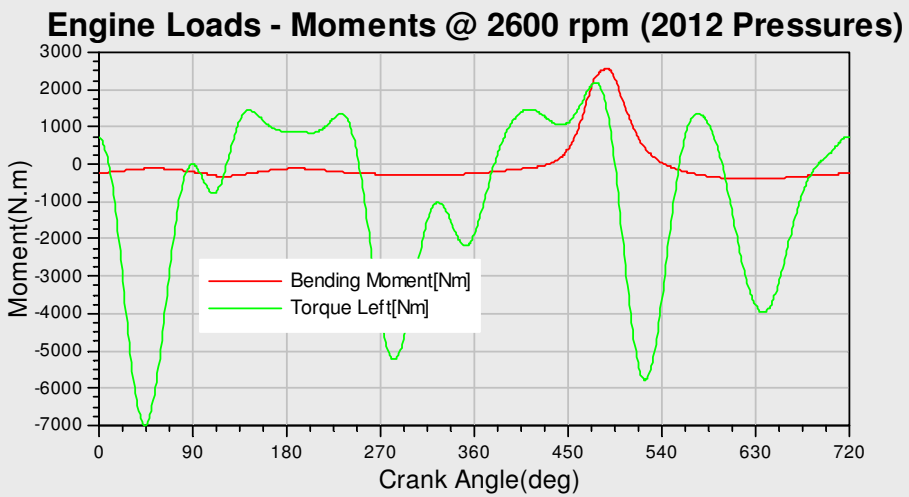


4. Dynamic Loads



Min Y	at X	Max Y	at X	Mean Y (arith.)	Mean Y (geom.)	Mean Y (int.dX)
0	0	0	0	0	n.d.	0
-21113.4	0.025	11204	0.0217949	-1133.56	n.d.	-1135.13
-176054	0.0236538	19974.4	0.000448718	-22442.6	n.d.	-22501
6461.54	0.0419872	176352	0.0236538	29382.5	21056.2	29396.1

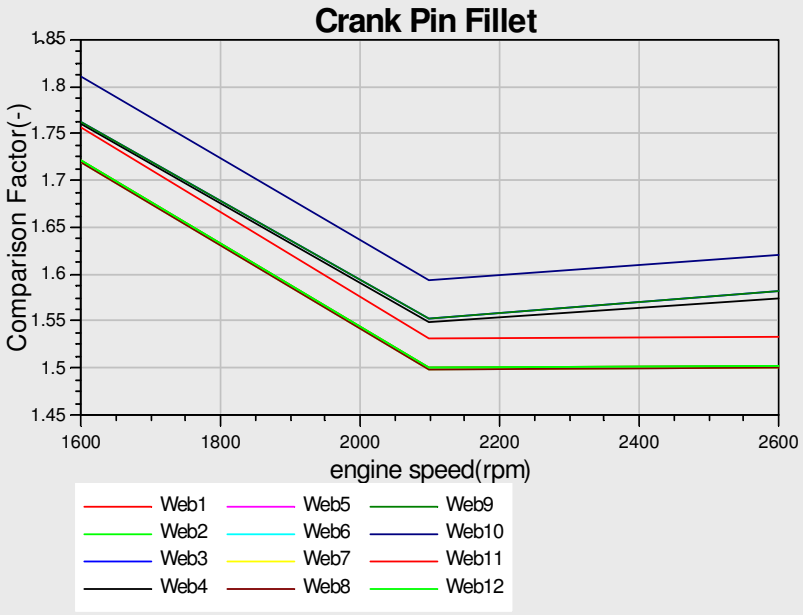
Bending Force = 176352 [N]

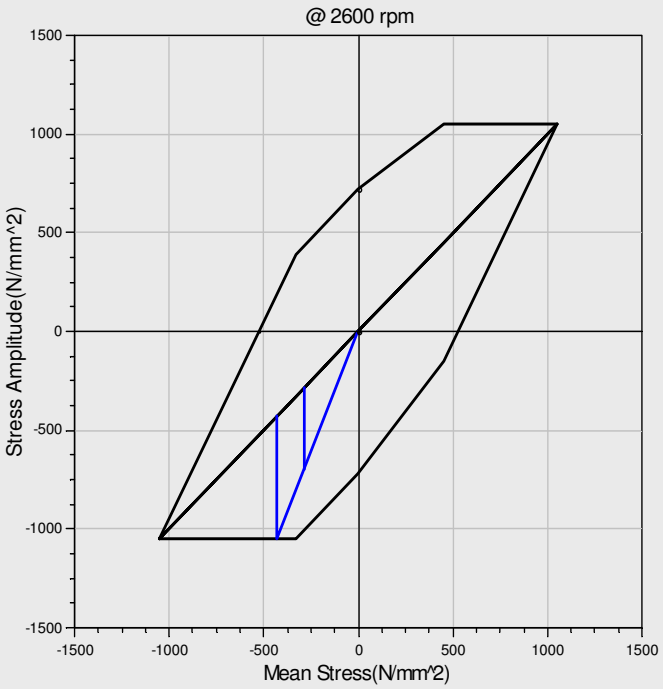


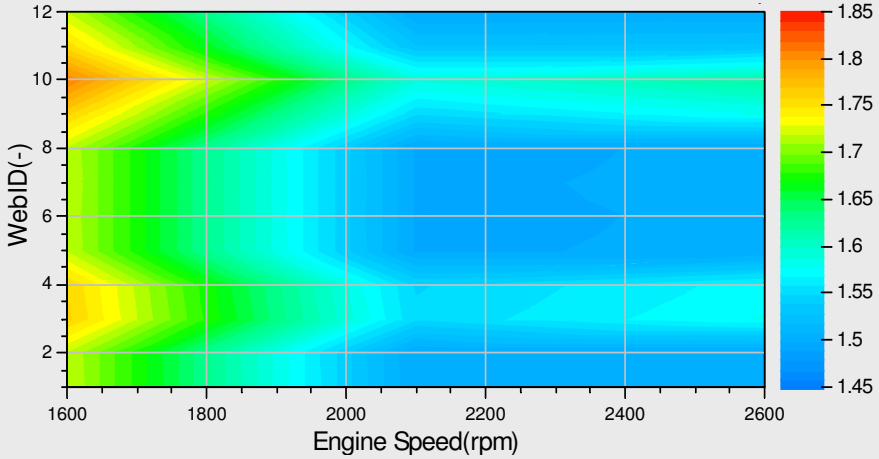
Min Y	at X	Max Y	at X	Mean Y (arith.)	Mean Y (geom.)	Mean Y (int.dX)
-394.334	637	2577.04	487	-24.6401	n.d.	-24.3419
-6991.46	44	2188.84	476	-956.717	n.d.	-959.043

Torque = 2 [kNm]

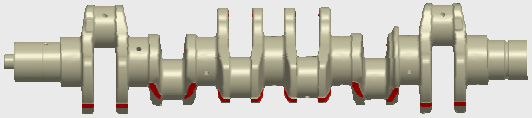
4. Dynamic Analytical - Safety Factor





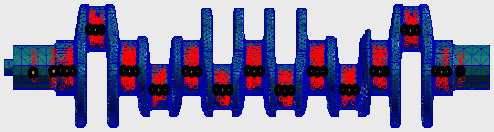


5. Flexible Analysis - Crankshaft Mesh

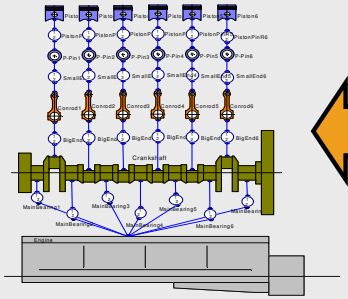


CAD Model

Modal analysis



Master Nodes &
Rigid connections



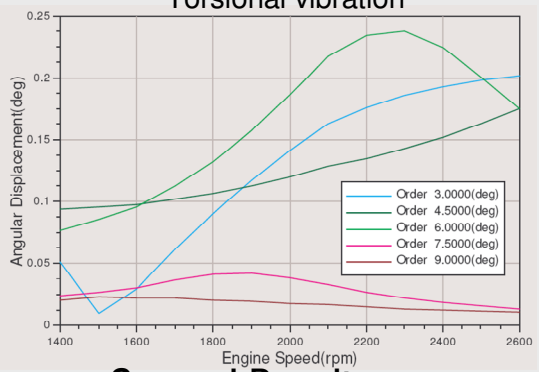
Dynamic Analysis
Joints Definition

Name	Size	Type
.job		File Folder
Crankshaft.bdf	19,108 KB	BDF File
Crankshaft_MFF.OUT4	8,184 KB	OUT4 File
Crankshaft.OUT4	1,174 KB	OUT4 File
Crankshaft_X2OA.OUT4	607,123 KB	OUT4 File
Crankshaft.MASTER	2,080 KB	MASTER File
Crankshaft.OUT2	18,544 KB	OUT2 File
Crankshaft.DOFT	2,599 KB	DOFT File

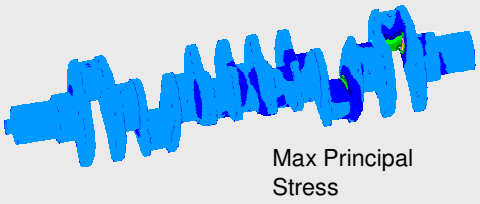
Results from
sub structuring

Dynamic Equivalent
Substitute Model

Torsional vibration

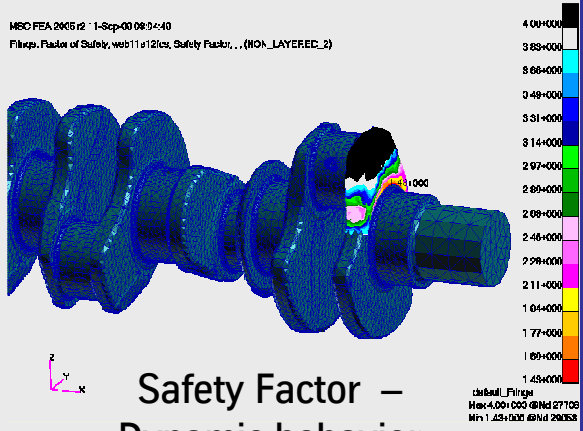


General Results –
Dynamic behavior



Max Principal
Stress

Stress Recovery –
Dynamic behavior

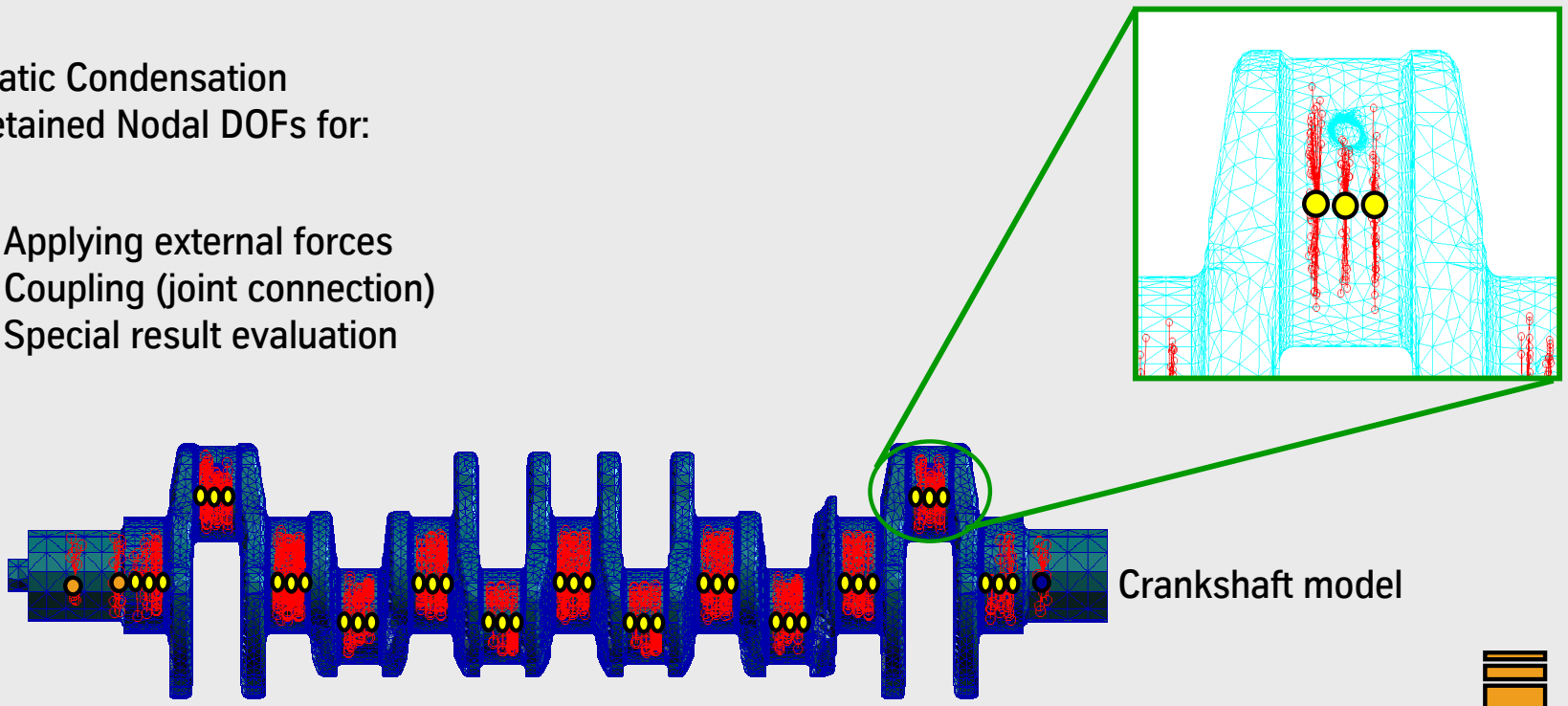


Safety Factor –
Dynamic behavior

5. Flexible Analysis - Crankshaft Sub-structuring

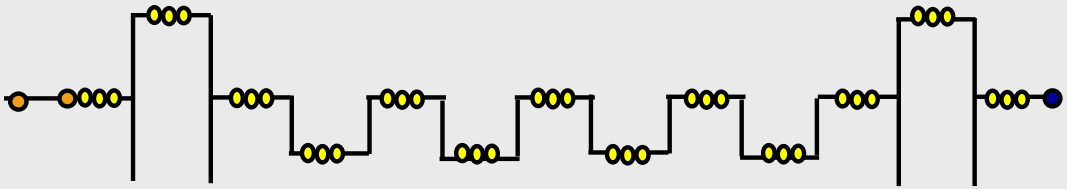
Static Condensation
Retained Nodal DOFs for:

- Applying external forces
- Coupling (joint connection)
- Special result evaluation



Crankshaft model

Condensation

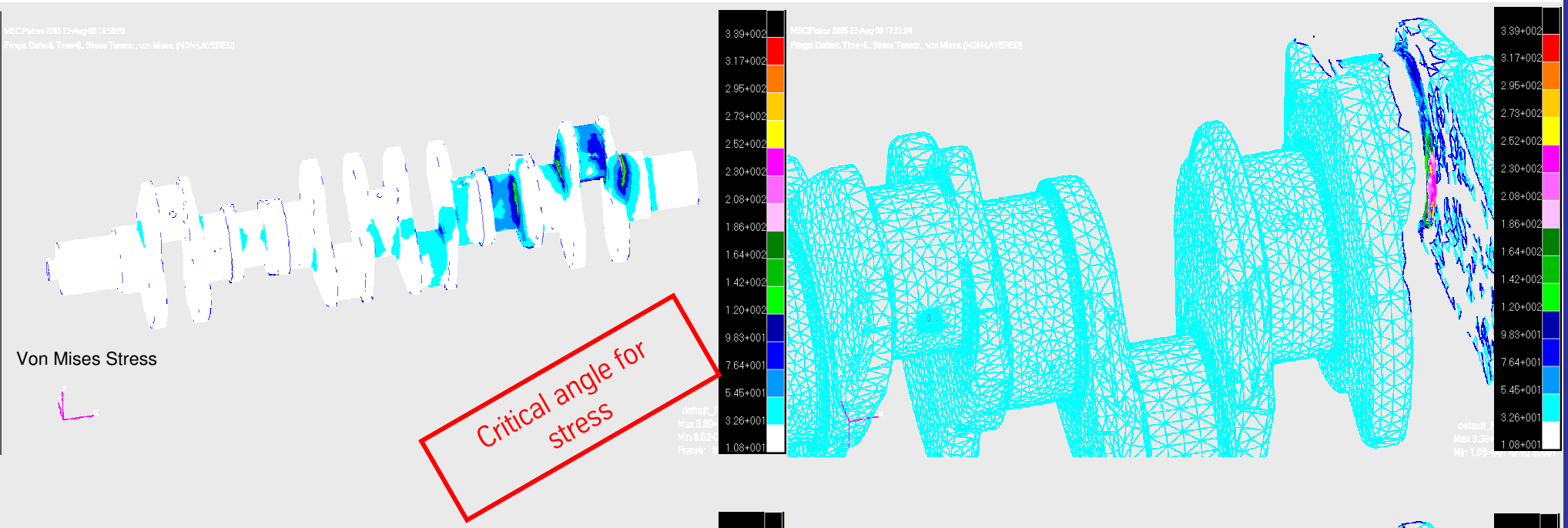


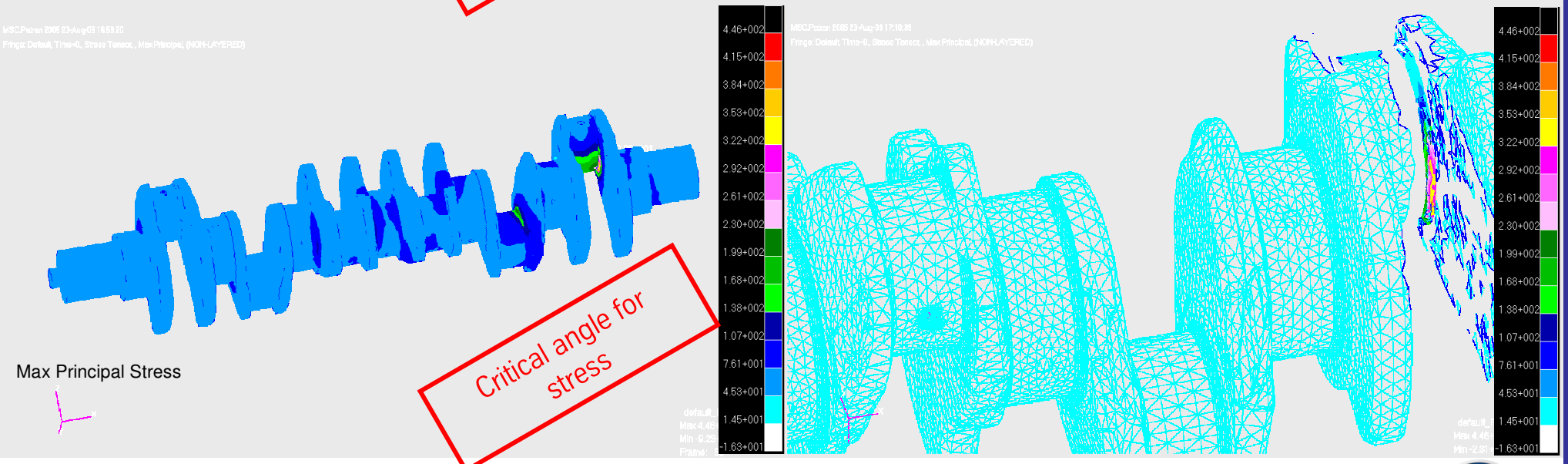
Dynamic Equivalent
Substitute Model

*BDF, *MFF.OUT4,
*OUT4,
*X2OA.OUT4,
*OUT2, *DOFT

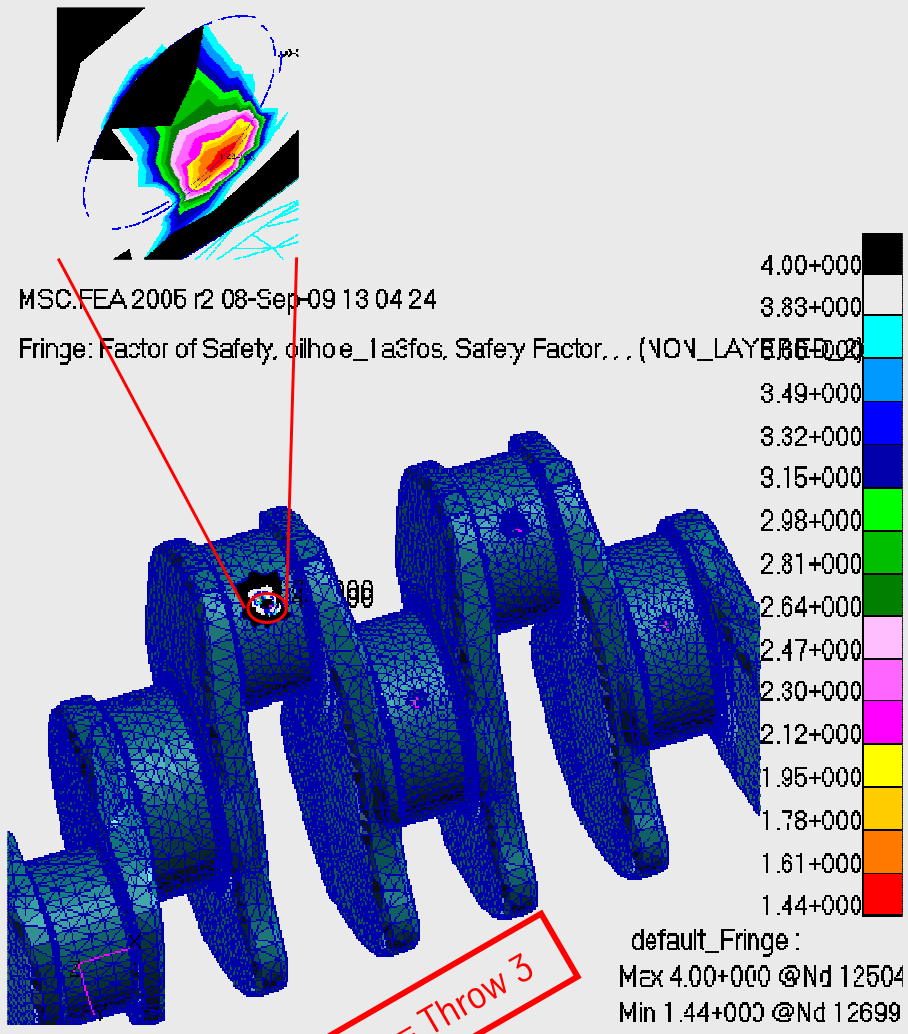
Elements: 280.000
Nodes: 75.000
Type: Patran Tet4

5. FEA Dynamic Results @ 2600 [rpm]

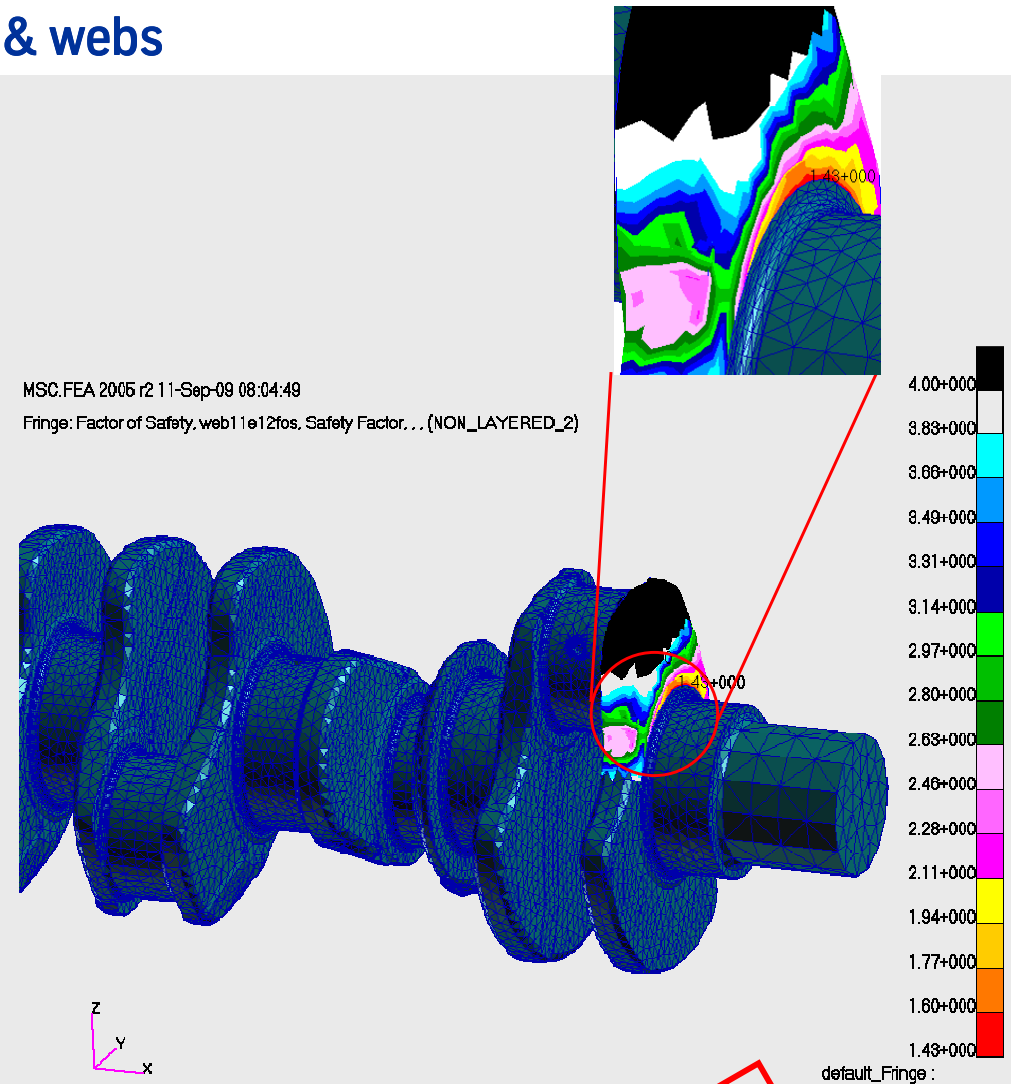




5. MSC Fatigue - Factor of Safety at oil hole & webs

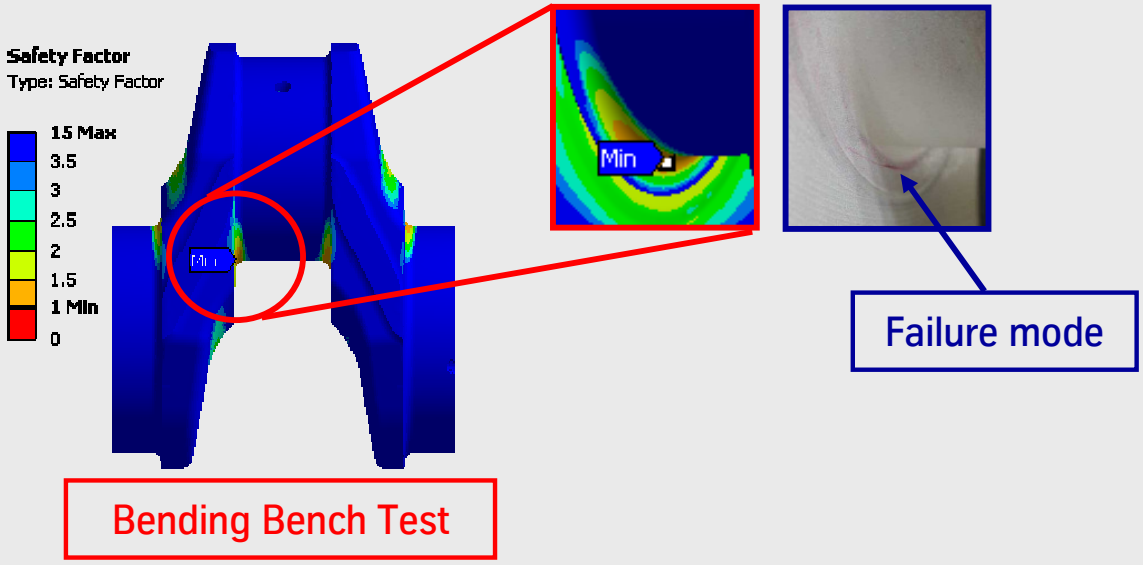


Most critical oil hole = Throw 3

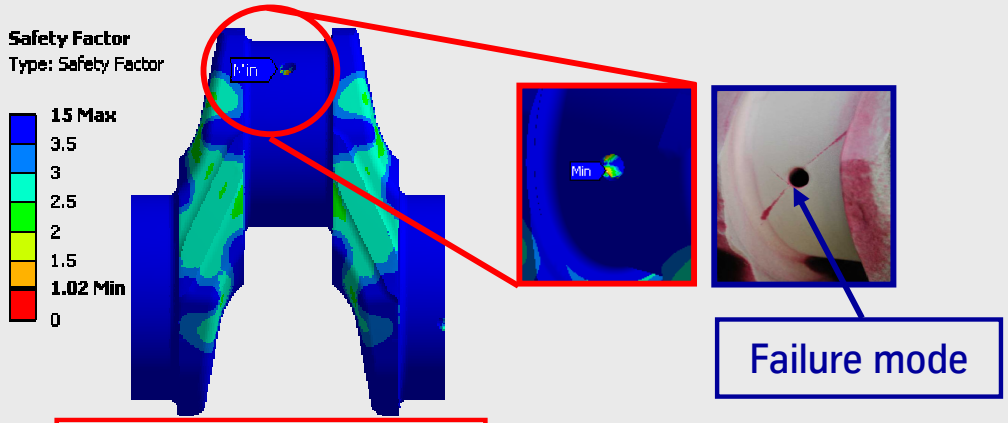


Most critical web = web 12

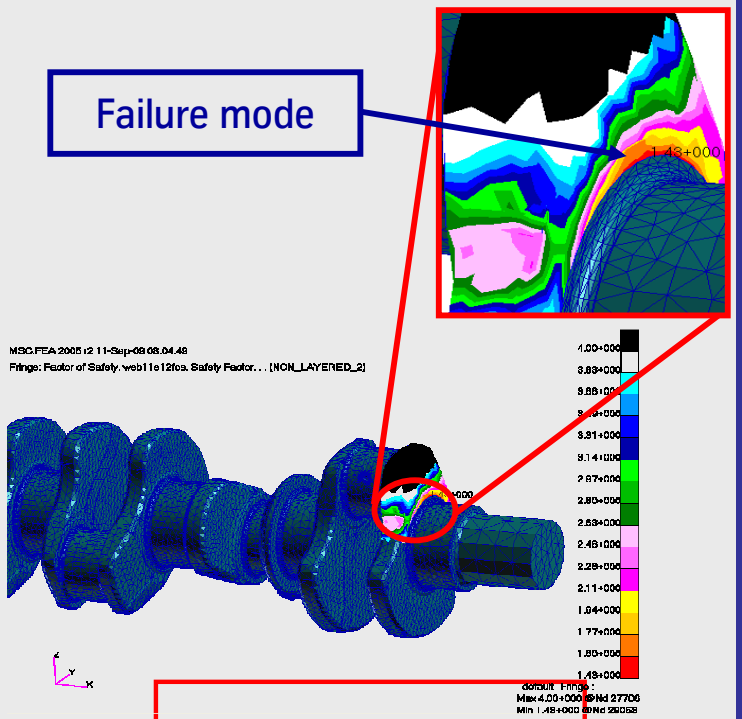
6. Conclusion



Bending Bench Test



Torsion Bench Test



Crankshaft under virtual Engine operation

6. Conclusion

Dynamic analysis:

- ✓Different boundary condition from bench test;
- ✓Equivalent failure mode under engine operation;
- ✓Better accuracy for predicting the behavior under engine operation;
- ✓Great potential for optimization;

7. Final

Thank you!

Obrigado!

Danke schön!