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MECHANICAL ANALYSIS OF A BOILER WATER CIRCULATION PUMP

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ABSTRACT

In previous investigations on life with flexible driving were highly stressed components predominantly in hot continuous pressurized part of power plants in the foreground. However cases of damage and subsequent studies on peripheral components such as the boiler circulation system (boiler circulating pump) showed that a potential failure as well as a high hazard potential respectively great consequential damage can occur when such components are operated under different conditions. To avoid damages and losses resulting from damage to peripheral components, these components have to be subjected to further analysis. Here especially the pump housing is in the focus.

INTRODUCTION

Due to the “Energiewende” and the corresponding increasing of renewable energy generation the requirements of power plants have changed. As the plants have been designed for a static load base mostly, they are more and more faced with a dynamic operation and a flexible response time. This change of operation has a big influence on the installed piping system and components like vessels, fittings and pumps. All this components are loaded with a higher strain as in the original design calculation considered. Especially for the boiler water circulation pumps only static load cases have been considered in most of the cases. Due to customer requirements or for internal validation some simplified fatigue evaluations were calculated in the past. The incident at the Staudinger power plant in the year 2014th can be considered as a turning point in the computational evaluation of the housings.

The presentation shows the process how the computational effort at KSB has changed by this incident. It is shown how the case was assessed by calculation before the incident and how it is currently investigated.

There are certain details of this modeling shown for example the modeled components and the mesh quality. The applied boundary conditions in the model are discussed. Thereby the heat transfer coefficients, the used contact settings and the bolt pretension will be explained. Another important aspect is the created load spectrum (transients!). This is created in close cooperation with the operators for the current calculations. Thereby representative measurement data at selected positions at the pump housing are transferred to KSB. KSB created from this data covered load collectives.

On the other hand the number of cycles of each transient were specified from the power plant. This load spectrum is absolutely constitutive for the quality of the results. The closer the load spectrum to reality, the more accurate the results. In the presentation an example of such a load spectrum is represented. The resulting usage factors are reported in accordance with KTA (AMSE). The places with the highest usage factors on the housing are shown as well.

To conclude the presentation, there is a view of the planned improvements in the procedure of calculation. In addition, the problems are named just when creating the load spectrum.

Text

1. Application for FEM at KSB

- Design
- Optimization
- Stress Analysis and Proof of Safety (incl. Seismic Qualification) for existing Design acc. relevant Codes as ASME, KTA, RCC-M, API, DIN, AD-Merkblatt
- Feasibility Study
- Failure Analysis
- Structural Safety
- Operability

2. Evaluation of BWCP prior Staudinger

- Standard: Evaluation of static load cases

  => Operating Condition + Pressure Test

  => Evaluation acc. ASME Sec. VIII Div.2

- Special: Fatigue analysis (state of the art)

  => Bexbach, Kentucky, Ivanpah, Ibbenbühren

  => Evaluation acc. ASME Sec. VIII Div.2

  KTA 3211.2

3. Current FEM Calculation of a BWCP

The aim of the calculation is to evaluate the fatigue strength of the new pump housings (bowls) with the improved design. The calculated pump type is a LUV Az (350bar / 380°C Design) with 1000mm bowl for conventional coal power plants. The calculation considers transients (Temperature + Pressure), bolt preload and the nozzle loads if they are available. The model is prepared in that way that further parts, e.g. bolts, heat barrier and the upper motor flange can be evaluated as well. The applied code is the KTA 3211.2 *(very conservative in comparison to* DIN) and the used program version is ANSYS 15.0 SP1.

4. Modeled Parts:

The used model is a 3D half model. A 3D half model is needed, because every critical location should be investigated by this calculation. Usually the critical locations are the intersection from the discharge nozzle to the pump housing or the radius between the pump bowl and the flange. Another reason for a 3D half model is, that additional the nozzle loads shall be considered, if they are available. As the nozzle loads are acting in all 3 direction (x, y and z) a 3D full model is needed. This model is very easy to create by reflecting the 3D half model. Following parts were modeled (see Figure 1):

- Pump Housing
- Upper Motor flange
- Heat Barrier incl. Insulating material (Ceramic)
- Main Closure Studs
- Nuts

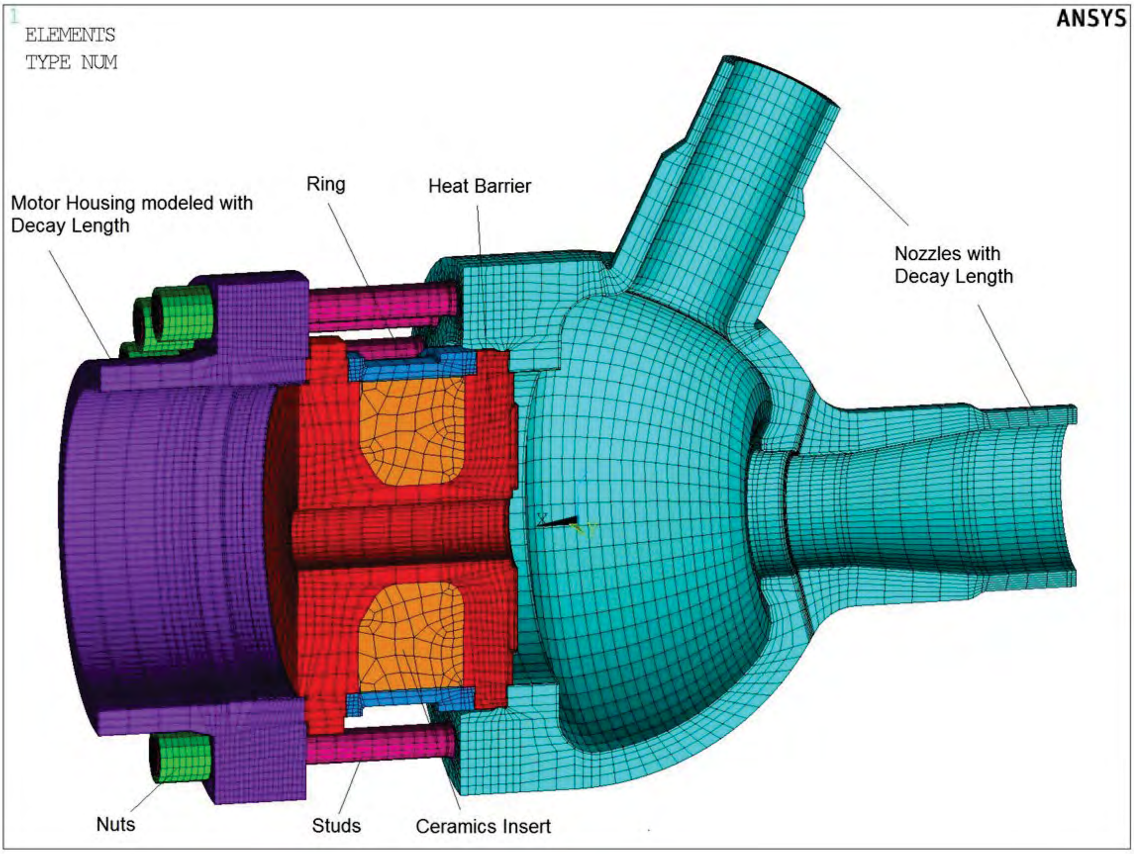

Figure 1: FEM modeled Parts

5. Transients

The transients are very important for the informational value of the calculation. If the plant is driven by different transients as those who were taken into account, the calculation becomes worthless.
The basis for the transients are recordings (control room of the plant) of temperature and pressure during a typical transient.

The next table shows an example of transients, which were used for the calculation (see Figure 2):

Description	T_{Start} in °C	T_{End} in °C	vT in K/min	P_{Start} in bar	P_{End} in bar	N
Cold Start *Step 1* *immediately after pump start*	30	140	20	1	4	2000
Cold Start *Step 2*	140	350	1	4	196	2000
Shutdown	350	30	0.3	196	1	2000
Warm Start	200	350	4	50	196	1000
Load Changes from Benson Operating	270	310	20	90	90	9400
Hot Start	250	350	20	50	196	6000

Figure 2: For Calculation used Transients

T = Temperature of system water

vT = Temperature variation speed

p = System pressure

N = Number of occurrences

6. Temperature Distribution

The temperature distribution, which is shown in Figure 3 is calculated at stationary condition. The conditions are:

T_{SYS} = 350°C => Temperature of system water

T_{Motor} = 60°C => Temperature of motor

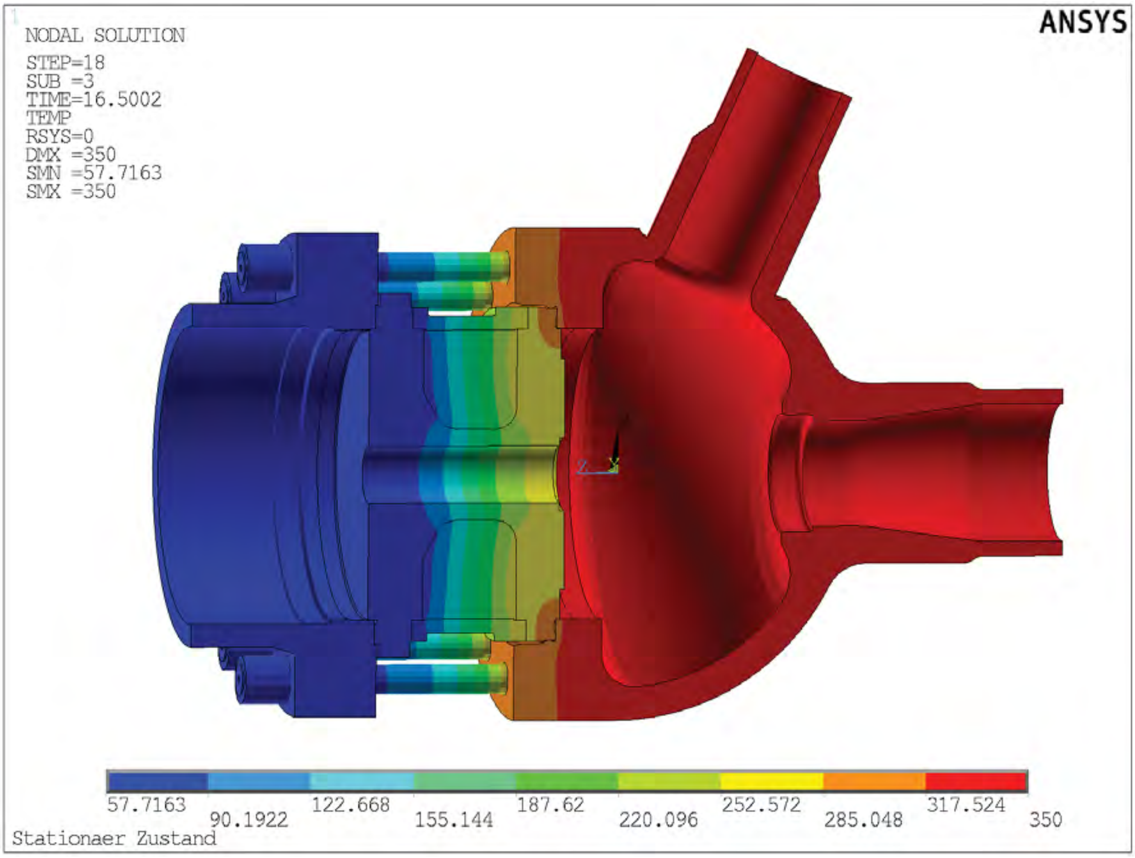

Figure 3: Temperature Distribution at stationary Condition

In that picture it can be seen, how the temperature decreases over the heat barrier. During the steady state conditions the pump housing is completely heated except the flange. The temperature decreases over the flange from 350°C to almost 280°C. One of the reasons for this is that the bottom side of the flange is not insulated, The other reason is that the main bolts pulling out the energy of the pump housing. This can also be seen by the temperature distribution of the bolts.

7. Stress Distribution (SEQV) in MPa

Figure 4 shows the stress distribution at stationary condition, which are as follows:

P_{SYS} = 196bar => System pressure

F_V = 1700kN per Stud => Bolt preload

T_{SYS} = 350°C => Temperature of system water

In the past at the radius inside the pump housing between the bowl and the flange (red circle) were very high stresses during the stationary condition. With the improvement of the geometry in this area, which results in the shown big radius, the stresses are very low; now.
The figure also shows the high stresses in the bolts due to the bolt preload.
At the intersection between discharge nozzle and pump bowl there are also high stresses due bending and geometric effects => small radius at the outer surface of the discharge nozzle.

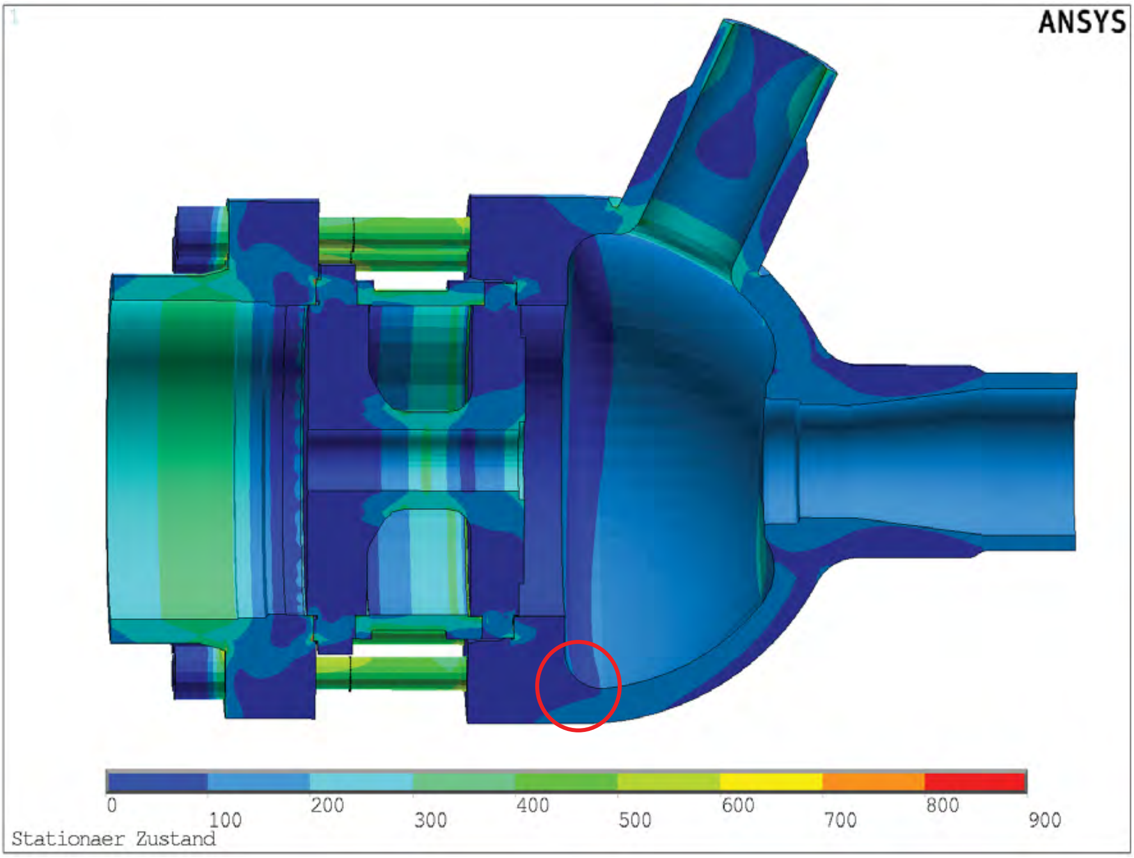

Figure 4: Stress Distribution at stationary Condition

8. Results

The usage factors were evaluated according KTA (similar to ASME). If we take into account that this code is for nuclear power plants the evaluation rules are very conservative for the depicted pump. The evaluation was also done according DIN 12952 and the calculated usage factors were much lower (factor 2 to 3) than the shown usage factors. The highest usage factors are all located in the radius between pump bowl and flange. The following highest usage factors are located in the intersection between discharge nozzle and pump bowl.

The highest usage factors amount to:

$UF_1 = 0.7$

$UF_2 = 0.7$

$UF_3 = 0.8$

$UF_4 = 0.7$

The position of the highest usage factors can be seen in Figure 5.

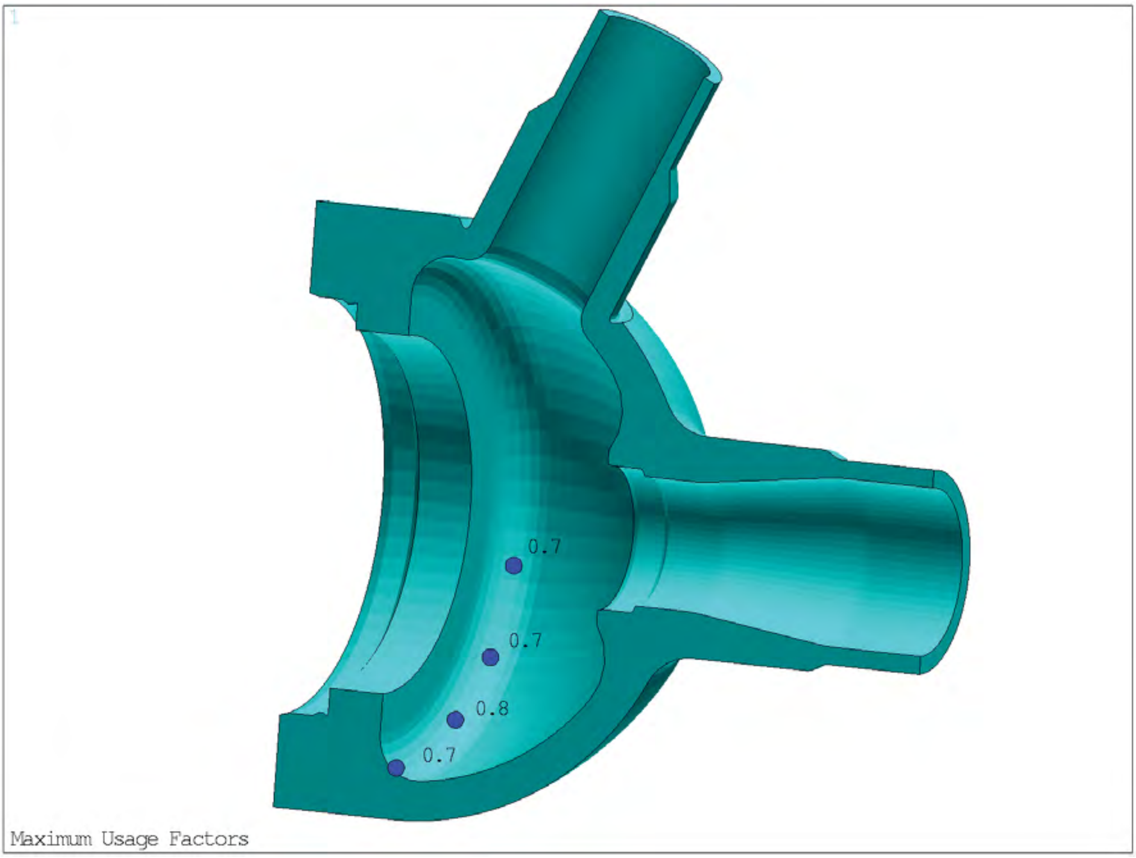

Figure 5: Highest Usage Factors

SUMMARY AND CONCLUSION

The calculation shows that the new pump housing design is prepared for the new requirements of the power plants.

Outlook:

The fatigue strength of new pump housings will be determined with this procedure. The aim is a “standardization“ of the modeling and the calculation, to save time. It is possible to evaluate further parts, e.g. bolts and/or heat barrier.

Discussion:

The specification of the transients has to be improved. A better coordination is needed here.

- Current => Transfer of records of the control room and a huge amount of data in Excel Tables for number of occurrences and operation mode.

  => A lot of Time is needed to evaluate the data, this is expensive and defective!

Conclusion:

The results shows that the usage factors in face of the rough transients and the conservative code are lower than 1! This means that the new pump housing geometry withstand the tough conditions without damage.